COMPUTATIONAL THINKING teacher resources

second edition


Inspire

Computational Thinking in K–12 Education

teacher resources second edition

Special Thanks

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We also want to thank the people who engaged with us to define *computational thinking* for a K–12 audience and contributed to the development of resources to help educators understand, value, and implement computational thinking in K–12 education.

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A Introduction to Computational Thinking Teacher Resources

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The skills needed to solve an equation, plan a project, or develop an outline for a writing assignment show similarities. They include important problem solving competencies that students need throughout their lifetime. Computational thinking (CT) can magnify problem-solving skills needed to address authentic, real-world issues. The Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) worked together to develop materials to help educators understand, value, and implement computational thinking in K–12 education. Visit iste.org/computational-thinking for more information.

With generous support from the National Science Foundation, ISTE and CSTA are taking leadership on this grant initiative to bring computational thinking skills into formal education for students in K–12 and beyond. We believe that today's students need these skills to meet workforce demands of the future and to help solve some of the most pressing, intractable problems of our time. Today's "digital natives" have grown up in a world where technology is evolving rapidly, creating new fields of study, new types of jobs, and requiring new sets of skills. As educators, we can help today's students gain computational thinking skills so tomorrow's professionals in medicine, history, law, education, or other fields, will be valued contributors in solving problems and making new advances.

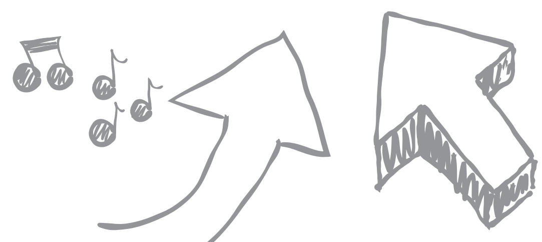
The Computational Thinking (CT) Teacher Resources reflect our commitment to the universal idea that CT can work across all disciplines and with all school-age children. CSTA and ISTE intend for the CT Teacher Resources to be a package of introductory materials that makes sense to and inspires teachers who don't teach computer science. In presenting drafts of these materials to a group of teachers, we heard comments including, "It's like putting on a new pair of glasses! I can see how I could implement CT with my students!" It is our hope that you, too, will experience a similar enthusiasm and willingness to explore CT as part of your own professional growth and look to bring CT into your classroom.

Ensuring that all students have the opportunity to learn the basics of CT in their K–12 education is a large and comprehensive goal. We believe that CT enhances many reform efforts such as STEM, the Common Core State Standards, NETS, and 21st Century Skills, as well as extending work in critical thinking and problem solving. CT adds another dimension of value to these efforts because of its focus on disciplined and creative problem solving made more relevant and powerful because of computing.

In the absence of a mandate, any new educational reform effort requires broad grassroots support, as well as materials and scaffolding necessary to support teachers in implementation. CT is not intended to be another "new thing" that teachers need to do. CT is a:

- Cross-curricular initiative, making all teachers responsible for introducing, reinforcing, and assessing CT skills in their students—and no one discipline bears the burden of ensuring students are fluent in CT when they graduate from high school.
- Problem-solving skill that gets progressively more sophisticated as students get older. It is critical that primary school teachers lay the foundation with age-appropriate activities that are buttressed with skills development throughout students' academic careers.
- Skill that most teachers are already building in their classrooms, but may not know it. By understanding CT, teachers are able to recognize and highlight it in their teaching. By exploring CT and gaining new CT skills, teachers can more fully embed it into their curriculum and assess those skills in their students.

As we have seen with the integration of technology in education, students are gaining skills to communicate, collaborate, create, and innovate in dramatic ways. With CT skills, students will recognize when a computer can help us to solve the problem. They will be able to recognize that computing enables them to collect and manipulate large data sets for decision making. They will be able to leverage the power of computing because they know how to program, or they will have the vocabulary, skills, and dispositions to collaborate with a computer programmer or designer to solve the problem.



Create

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The CT Teacher Resources include:

Operational Definition of Computational Thinking for K–12 Education

ISTE and CSTA achieved consensus among educators in the field around core skills and dispositions that describe what CT skills all students should have when they graduate from high school.

Computational Thinking Vocabulary and Progression Chart

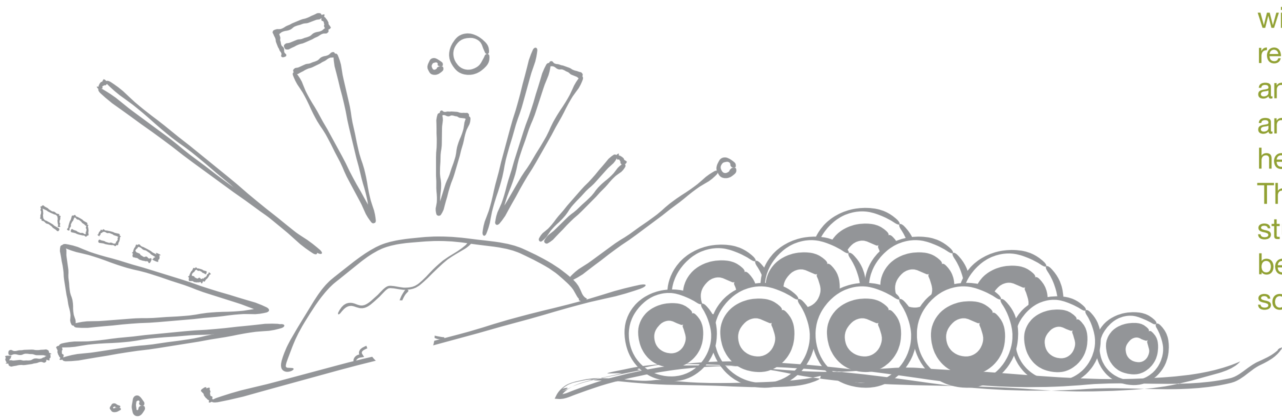
This chart "unpacks" the operational definition by listing CT concepts implicit in the operational definition, as well as "bite-sized" examples at each grade band and in multiple content areas. While not a scope and sequence of skills, the chart shows a progression of CT activities that grow more sophisticated as students progress through their education.

Computational Thinking Learning Experiences (CTLEs)

The CTLEs are a small sample of prototype learning experiences formatted to resemble a lesson or unit plan. The eight CTLEs include a "CT Guide on the Side" meant to emphasize CT components, dispositions, and vocabulary included in the CTLE. The CTLEs illustrate CT highlighted in activities, why these are considered CT activities, and how you may evaluate your own lesson or unit plans by recognizing, highlighting, and embedding CT into them.

Computational Thinking Scenario

This narrative illustrates how CT is implemented and assessed in the classroom.



The companion to these resources is the Computational Thinking Leadership Toolkit, which makes the case for the power of CT, why CT is important for all students, and why CT is important now. CT is a very new field and few, if any, people would call themselves CT experts—including CSTA and ISTE. Jeannette Wing set out to articulate CT in 2006. We are not updating a well-established curriculum. We are beginning to define the CT domain for K–12 education. So, you will likely discover that the CT skills are not discrete; they overlap and intersect with each other; and sometimes understanding CT can be challenging and messy because of the inconsistencies and lack of clear answers.

Our hope is that you develop an understanding of CT and recognize the CT skills and dispositions you are already including in your lessons and units. Consider re-examining your current lessons or units with an eye to extending an activity with CT, take part in a professional learning network to engage with others new to CT, find other CT resources (there are excellent CT activities and lesson plans from other organizations), and request other CT resources that would help you implement CT in the classroom. The promise of CT is that it can empower students with the skills they need to become effective and confident problem solvers in a complex world.

Wonder

B | Operational Definition

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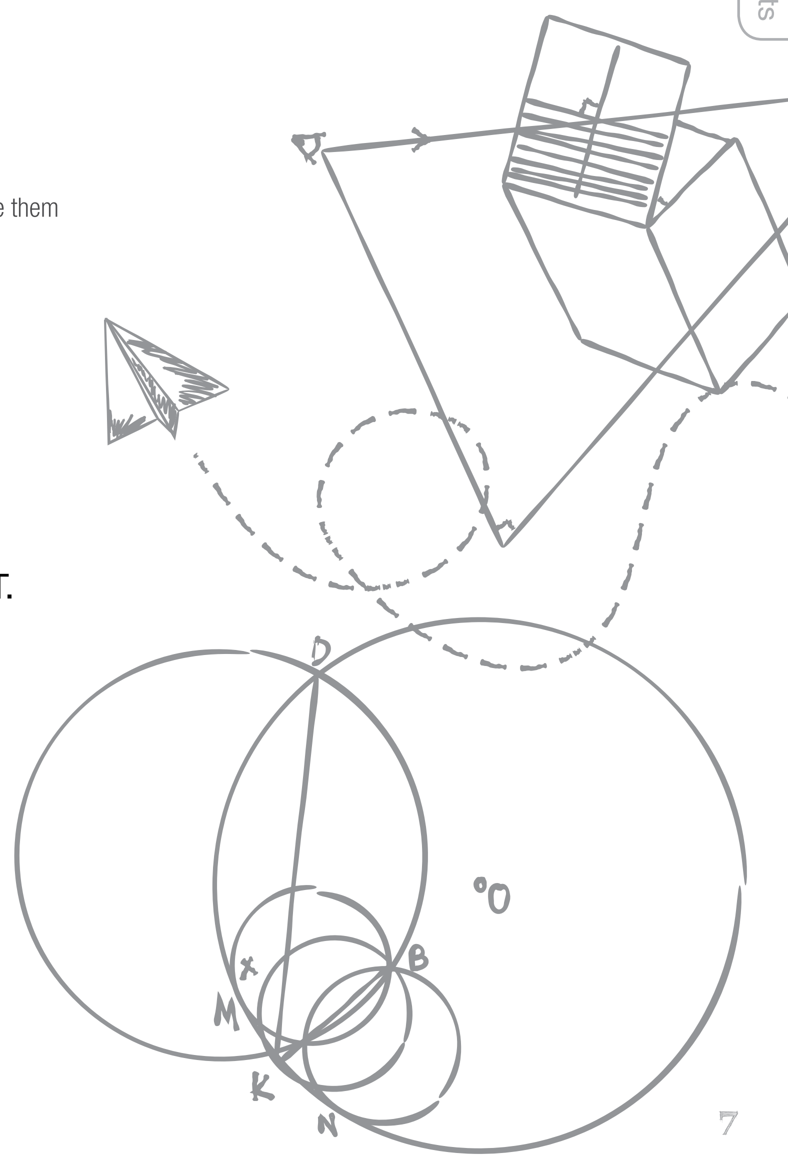
ISTE and CSTA collaborated with leaders from higher education, industry, and K–12 education to develop an operational definition of CT. The operational definition provides a framework and vocabulary for CT that will resonate with all K–12 educators.

CT is a problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them
- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem-solving process to a wide variety of problems

These skills are supported and enhanced by a number of dispositions or attitudes that are essential dimensions of CT. These dispositions or attitudes include:

- Confidence in dealing with complexity
- Persistence in working with difficult problems
- Tolerance for ambiguity
- The ability to deal with open-ended problems
- The ability to communicate and work with others to achieve a common goal or solution



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C | CT Vocabulary and Progression Chart

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	Definition	Grades PK to 2	Grades 3 to 5	Grades 6 to 8	Grades 9 to 12
Data Collection	The process of gathering appropriate information	Conduct an experiment to find the fastest toy car down an incline and record the order of cars across the finish line in a chart.	Review examples of writing to identify strategies for writing an essay.	Design survey questions to gather appropriate information to answer questions (e.g., asking fellow students if they were absent from school in the past month and whether they were suffering from the flu).	Students develop a survey and collect both qualitative and quantitative data to answer the question: “Has global warming changed the quality of life?”
Data Analysis	Making sense of data, finding patterns, and drawing conclusions	Make generalizations about the order of finishing a toy car race based on the characteristics of the car with a focus on weight. Test conclusions by adding weight to cars to change results.	Categorize strong and weak examples of writing samples to develop a rubric.	Produce and evaluate charts from data generated by a digital probe and describe trends, patterns, variations, and/or outliers represented in the chart.	Use appropriate statistical methods that will best test the hypothesis: “Global warming has not changed the quality of life.”
Data Representation	Depicting and organizing data in appropriate graphs, charts, words, or images	Create a chart or a line drawing that shows how the speed of a toy car changes when its weight is changed.	Match each writing sample to the rubric and create a chart showing which example best fits in each category of the rubric.	Plot data using different charting formats and select the most effective visual representation strategy.	Groups of students represent the same data in different ways based on a position relating to the question: “Has global warming changed the quality of life?” Different representations may result in varying conclusions.
Problem Decomposition	Breaking down tasks into smaller, manageable parts	Create directions to a location in the school by breaking the directions down into smaller geographical zones. Join the sections of directions together into a whole.	Develop a plan to make the school “green.” Separate strategies such as recycling paper and cans, reducing use of electricity, and composting food waste.	In planning the publication of a monthly newsletter, identify roles, responsibilities, timeline, and resources needed to complete the project.	Consider the large-scale problem: “What does it take to become a rock star?” Break it into smaller parts. Discuss what variables are within a student's control and what variables are determined by outside factors.
Abstraction	Reducing complexity to define main idea	With many sizes and colors of three-sided shapes, the abstract is a triangle.	Hear a story, reflect on main items, and determine an appropriate title.	After studying a period in history, identify symbols, themes, events, key people, and values that are most representative of the time period (e.g., coat of arms).	Choose a period in politics that was most like the current one by analyzing the essential characteristics of the current period.

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	Definition	Grades PK to 2	Grades 3 to 5	Grades 6 to 8	Grades 9 to 12
Algorithms & Procedures	Series of ordered steps taken to solve a problem or achieve some end.	Create a set of directions from the school to the major landmarks in the neighborhood.	Design a board game and write instructions to play. Test instructions on peers trying to play the game. Refine instructions with feedback from peers who played the game.	Program a robot to find its way out of a maze such that given any maze, the robot could exit successfully within a specified time period.	Discuss the decision-making process for choosing a college, then create an algorithm that describes that process. The algorithm will be able to handle unknown variables, such as where friends are attending, availabilty of financial aid, and admission success, to come to an unambiguous decision.
Automation	Having computers or machines do repetitive or tedious tasks.	Converse with a classroom in another state or country to learn about their culture using Internet-based tools to replace writing letters.	Investigate what automation is through real-world examples, like barcodes, teller machines, and library bar codes.	Program a sensor to collect pollution data (set timers with probes) and then use a computer program to sort the readings from maximum to minimum CO_2 levels.	Debate the merits of learning skills and information that are rarely necessary today because of automation. These skills might include long division, deriving square roots, spelling, statistical formulas, memorizing historic dates, etc.
Simulation	Representation or model of a process. Simulation also involves running experiments using models.	After a set of directions has been created, act out the steps to be sure they are correct.	Create an animation to demonstrate the understanding of a process.	Use a model of a simple ecosystem to conduct experiments that answer what happens to the ecosystem if some percentage of the producers die. The user controls the percentage that dies off.	Create a spreadsheet to simulate the "Birthday Problem" (How many people must be in a room for there to be at least a 50% chance that at least two have the same birthday?). Use the same model to answer the question for three people having the same birthday.
Parallelization	Organize resources to simultaneously carry out tasks to reach a common goal.	Based on a set of criteria, break the class into two groups. Have one group read aloud while the other group provides humming background music. The goal is reached, but the whole is better than the individual parts.	Teachers facilitate in planning team project timelines, roles, and assignments and working together to complete components (how do we break up the tasks, what tasks have to be done sequentially and others simultaneously, check ins, meeting deadlines?).	Student teams plan production of a video, including script, props, and roles of the team in producing the video. Identify tasks that will be carried out simultaneously, and milestones where they check in, and plan, and put things together.	Describe the sequence of activities by each of the armies leading to the Battle of Waterloo. Include both physical activities (e.g., recruit troops) and intellectual activities (e.g., pick troop positions).

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D CT Learning Experiences

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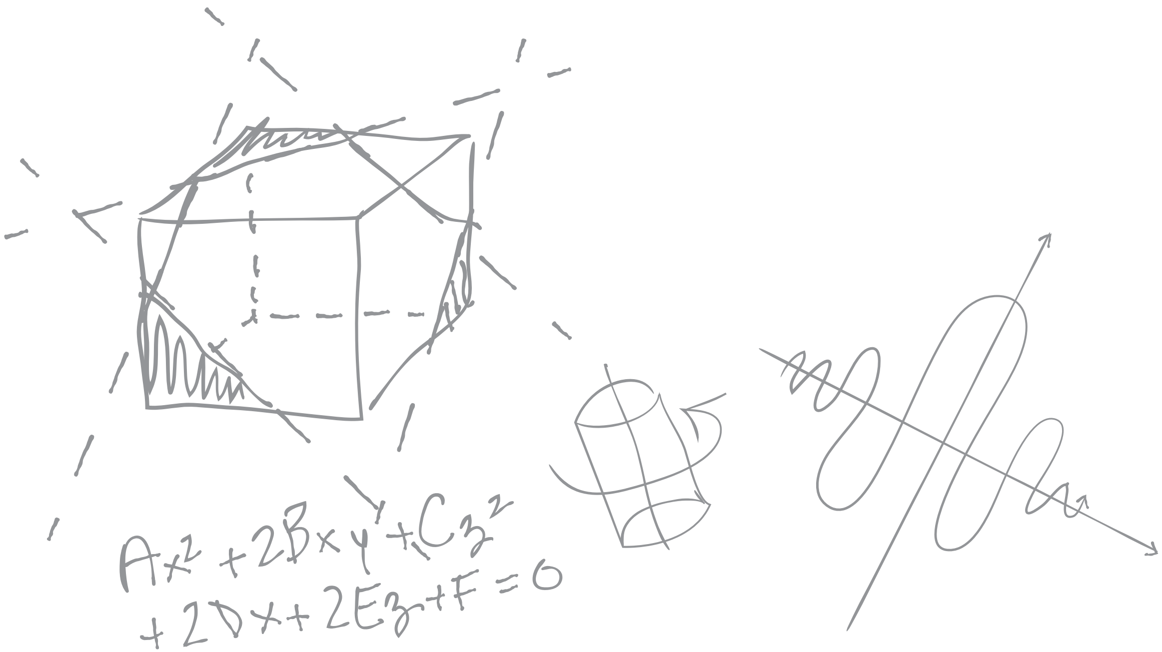
Many thanks to the individuals who contributed to writing the Computational Thinking Learning Experiences (CTLEs), including Kathy Hayden, Youwen Ouyang, Peggy Kelly, David Barr, Jim Pollard, Josh Block, and Irene Lee.

The nine CTLEs are a small sample of prototypes for what CT can look like at various grade levels and content areas. They are intended to illustrate CT in a format familiar to classroom teachers. The small sample of CTLEs doesn't allow for a comprehensive integration of CT, and they are not meant to. They are tools for understanding and provide guidance by example for examining your own lesson and unit plans.

No definitive CT assessment is available yet. CT is both discrete skills (algorithmic thinking, abstraction, etc.) and the composite skill of all of the components together (the entire operational definition of CT), which makes for powerful and robust problem solving. We come to terms with these divergent ways of describing CT through an analogy. A student is considered to be doing math if he or she is learning addition. A student is considered numerically literate if he or she knows addition, subtraction, division, and multiplication. The student has learned each of those math components separately. It is the same with CT, thus the reference to computational thinking and computational thinking skills.



How to use the CTLEs

The CT skills and dispositions, based on the operational definition of CT for K–12 education, are addressed within the CTLEs and are listed up front for easy reference.

The **CT skills are listed in black**, and the CT dispositions are listed in blue throughout the CTLE.

Activity:
Adapted from Read, Write, Think.

1. Introduce the lesson by telling students they will write an effective opinion piece.
2. Students read and listen to a variety of opinion pieces.
3. Students identify examples of strong and weak persuasive writing and [record commonalities] on a graphic organizer.
4. Class [uses graphic organizers] to generalize criteria for an effective opinion piece and agree on the criteria for a [rubric]. This rubric helps students answer questions:

   How shall I write my piece? What are the [trade-offs]? What are the important things? Are there conflicting criteria?

CORRELATION:
words or phrases surrounded by red brackets ([ ]) within the body of the CTLE indicate the activity that correlates to CT skills, dispositions, or vocabulary; and correlates to the appropriate CT Guide on the Side comment.

The CT vocabulary is highlighted throughout the CTLE and is based on the definitions as published in the CT Vocabulary and Progression Chart (pages 8–9).

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Automating solutions through algorithmic thinking
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem solving process to a wide variety of problems
- Tolerance for ambiguity

[Record commonalities] The process of studying the examples, finding commonalities, categorizing them, finding patterns helps students to logically analyze and organize data.
Highlight Data Analysis: Making sense of data, finding patterns, and drawing conclusions.

[Use graphic organizers] The software and the resulting chart show a pattern that emerges of the characteristics of the opinion pieces in an organized way
Highlight Data Representation: Depict and organize data in appropriate graphs, charts, words, or images.
Agree on criteria: Ability to communicate and work with others to achieve a common goal or solution

[Rubric] An abstraction of the criteria for a good opinion ... and informs student decisions about how to write ... aper.
...ht Abstraction: Reducing complexity to define ...dea

...-offs] Students need to make decisions about ... pinion piece that balance what is most important ... iteria constraints, like word count or structure, to ... e the most efficient and effective combination of ... and resources.

CT Guide on the Side:

This guide provides a correlation to the CT skills, dispositions, and vocabulary throughout the CTLE. It also includes commentary, where appropriate for why an activity is considered a CT activity.

Directions for integrating the CT Guide on the Side Comments:

CTLE Users Guide Legend

- CT Skill
- CT Disposition
- CT Vocabulary

Skill: The commentary includes a description of a CT skill, how it relates to the activity, or why that activity is considered CT.

Disposition: This correlation is to help you and your students recognize the attitudes needed to become a computational thinker.

Vocabulary: Use the correct vocabulary with your students, so they can recognize the vocabulary and transfer the use of them to other projects and classes.

Teachers can use the CTLEs as models for re-examining lesson and unit plans to identify where CT currently exists and where an added activity or extension could build CT into a lesson or unit.

Disclaimer: The CTLEs are designed to shine the light on CT in a format familiar to teachers. They are intended to help correlate CT to the activities. We encourage you to fill in instructional elements necessary to implement any of these CTLEs.

This material is based on work supported by the National Science Foundation under Grant No. CNS-1030054.

1 Sequencing
Language Arts Grades PK–2

Excite

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Automating solutions through algorithmic thinking.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Generalizing and transferring this problem-solving process to a wide variety of problems.
- Tolerance for ambiguity.

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Outcomes:

The student is able to provide a set of sequential directions for accomplishing a task.

Standards:

Grade 2 Common Core English Language Arts Writing Standards

Evidence:

1. The task is eventually carried out.
2. Revision takes place when the directions or sequence of steps is noted to be incorrect.
3. Upon being questioned, the student is able to find a more direct way to accomplish the task. Or, if the original directions were accurate, the student is able to provide an alternative way and explain why the alternative is not the most efficient or direct.

Activity:

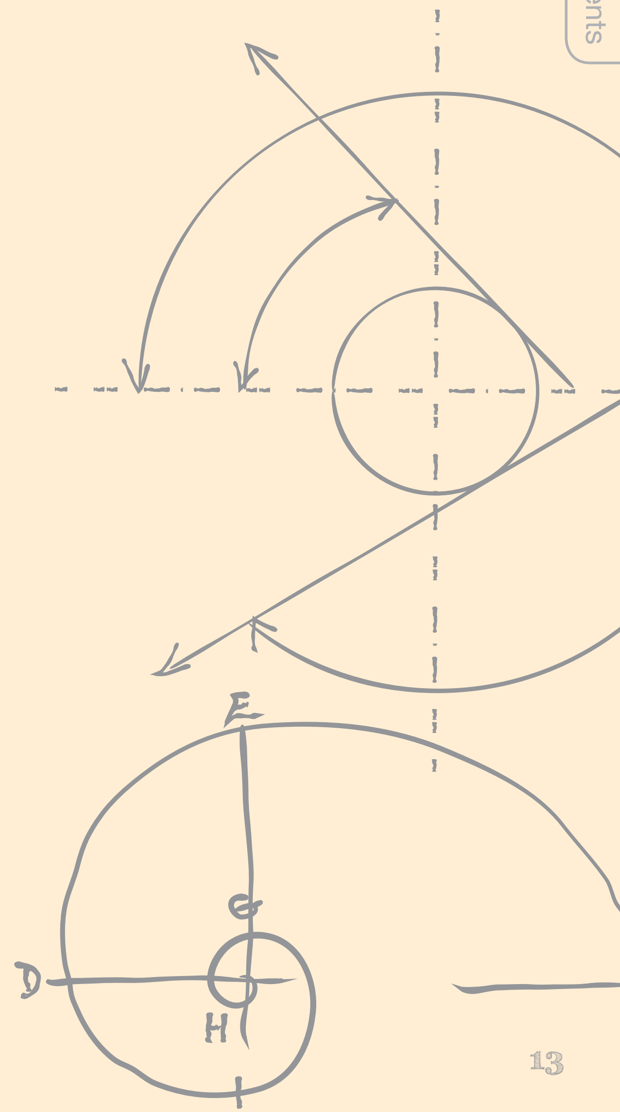
PART I - Geometry and Measurement Connections

This activity can be used by parents and teachers and revised to become increasingly more complex. The activity focuses on giving explicit directions using language that is accurate and directional. The initial activity focuses on using vocabulary words, such as forward/backward, right/left, possible link to degrees or angles (right angle), and number of steps to be taken. Extension activities transfer the ability to give directions to different contexts.

The activity begins with stating the problem/scenario:

> *My eyes are tired, and I just cannot see well. I don't know how to get to the door from where I am.*

For very young children, the questioning may start in an open-ended fashion: "How do I do that?" For older children, the activity can begin more directive, "Give me directions on how to…." This activity can be embedded within the classroom as a warm-up or as part of oral language development with a focus on right/left, forward/backward, etc. The level of complexity depends on the developmental level of the students and their level of writing skills.



1. "Please [give me directions] to get to the front door. I am only going to do exactly as you tell me.... Jorge, can you give the first direction?" Do not embellish the student's directions beyond what is provided by him/her. Do exactly as directed. Allow the student to troubleshoot his/her own response based on how you move.
2. As the teacher or parent, follow the directions as stated. If Jorge just says, "walk," then walk randomly. Encourage Jorge to provide as much language as he is capable of to direct you. Do not turn. Do not stop. If Jorge has counting skills, ask Jorge to estimate how many steps in each direction. Ask Jorge to give you directions on which way to turn, right/left.
3. At the conclusion of getting to the goal (door), ask Jorge to restate the directions. If he is not able to restate the directions, let the class help you fill in the missing steps.

PART II - Extensions

1. Have the children [write the directions] out first in pairs, then act out the directions with one acting and one checking. Direct the students to revise their directions based on their experience.
2. Block a pathway. Ask students to [find an alternative way] to get to the door.
3. Ask pairs of students to find three different pathways to the door. Ask them to [evaluate which pathway is the fastest or most efficient]. The student pair should be able to justify why one pathway is more efficient than another.
4. Have students provide a clear set of directions to [do other tasks]. For example:
   - Create a common lunch item such as a peanut butter and jelly sandwich.
   - Describe the steps to do a specific type of math problem.
   - Describe how to do a specific task of their choice—from brushing teeth to playing an instrument or performing a specific dance move.

CT Guide on the Side

[Give me directions] Students are forced to provide accurate, sequential directions, void of assumptions.

Highlight Algorithmic Thinking: Series of ordered steps taken to solve a problem or achieve some end.

[Write the directions] Student pairs deconstruct the pathway into segments and build the directions from what they see.

Highlight Problem Decomposition: Break down task into smaller, manageable parts.

[Find an alternative way] Tolerance for ambiguity.

[Evaluate the pathway] Looking at alternative options requires students to analyze possible solutions that are most efficient.

[Do other tasks] Students can generalize and transfer this experience of creating directions to other situations in which skills are required.

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Reinforces:

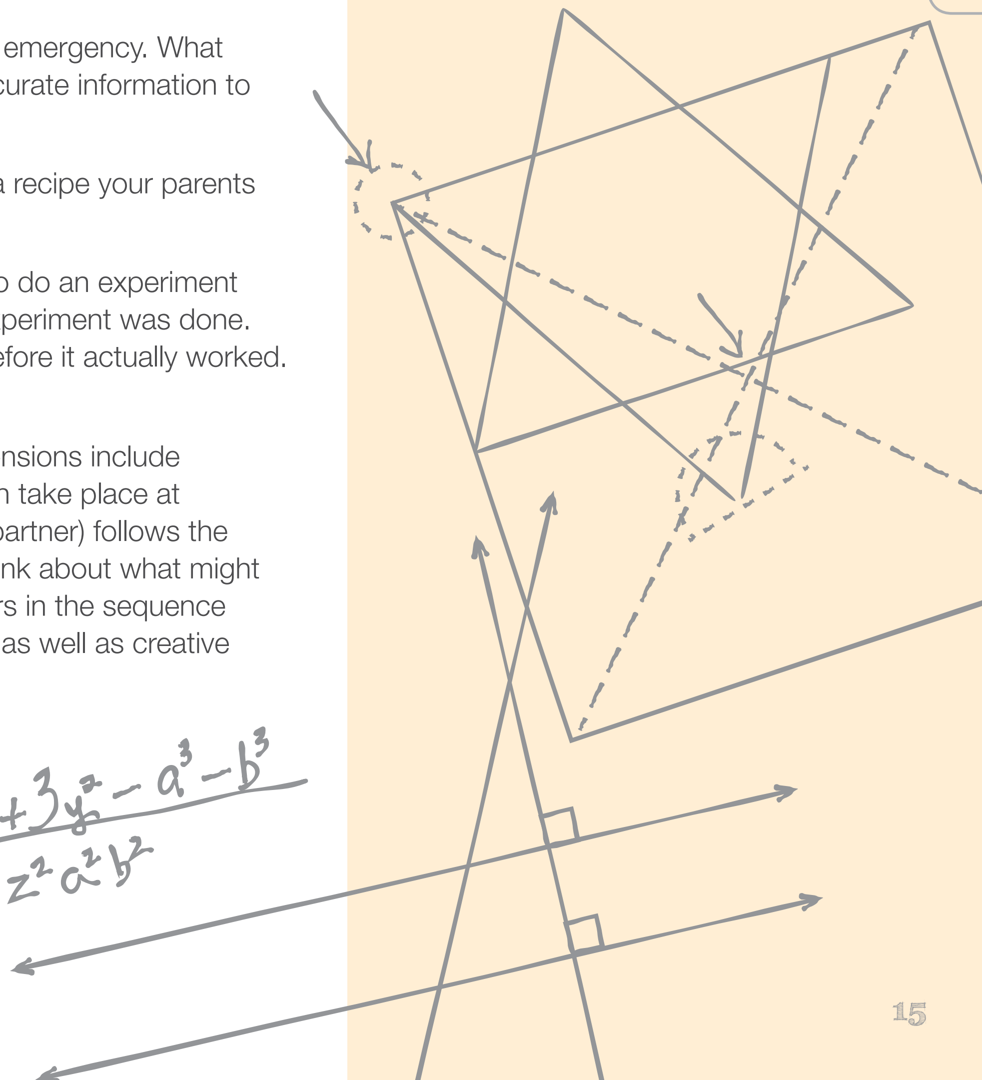
The activity reinforces sequencing and the impact of an incorrect sequence of steps. Being able to think logically about what happens first, second, third, is critical to thinking about how a task could be done. Finding alternative ways to accomplish the same thing allows students to find alternatives if the conditions change.

Connections to Vocations:

1. Police and fire departments often use this skill in the case of an emergency. What happens when a roadway is blocked? How do they provide accurate information to others on how to get to the emergency?
2. Cooks and chefs use directions to prepare your food. Imagine a recipe your parents have never used. How can the dish be made just right?
3. Scientists use directions in many ways. Sometimes they want to do an experiment again and need to know the exact order in which the original experiment was done. This is especially true if they tried the experiment many times before it actually worked.

Strategies:

The activity is a student-centered activity utilizing role-playing. Extensions include independent practice, perhaps in pairs and individual work that can take place at home. The classroom culture requires that the adult (and student partner) follows the directions, is accepting of the directions, and allows the child to think about what might not be working. Allowing the child to create alternatives, or fix errors in the sequence or directions is critical to having the child be open to error analysis as well as creative problem solving.



$$\sqrt[3]{\frac{(2xy)^2, (3ab+3x)^3}{x^3 y^2}} = \frac{5x^2+3y^2-a^3-b^3}{z^2 a^2 b^2}$$

2 Growing Plants

Interdisciplinary Grades PK–2

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Representing data through abstractions such as models and simulations.
- Automating solutions through algorithmic thinking.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Persistence in working with difficult problems.
- Confidence in dealing with complexity.
- The ability to communicate and work with others to achieve a common goal or solution.

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Outcomes:

- Provide students with the tools to overcome negative messaging, challenges, and unknowns (e.g., “I’m not sure what I’m doing, but I’m gonna do it because I care about it or it simply needs to get done.”).
- Understand how a plant develops from a seed.
- The ability to communicate and work with others to achieve a common goal or solution.

Standards:

Grade 2 Common Core Math Standards

Evidence:

1. Students are able to express how to overcome discouraging comments.
2. Students planted the garden and it grows.

Activity:

PART I - LITERATURE CONNECTIONS

1. Read the classic story, “The Carrot Seed,” by Ruth Kraus. The story is about a young child with a single-minded, unwavering commitment to cultivating a carrot from seed to harvested product. [He sticks with his gardening challenge] in spite of the unknowns and discouraging messages he hears from family members.
2. Prompt students with these questions:
   - “Let’s [summarize the story]—What is the story about?”
   - “How many of you have ever planted seeds in a garden? How many of you took care of the seeds until the plants were full grown? What does it mean to take care of the plants? It is hard work. If you have done this, you have been persistent. What does *persistent* mean? What was that experience like?”

CT Guide on the Side

[Sticks with gardening challenge] Persistence in working with difficult problems.

[Summarize the story] Choosing the main ideas is an abstraction.

Highlight Abstraction: Reducing complexity to define main idea.

- "Why do you think the boy's family members didn't think he could do this?"
- "What did you learn from the boy in the story?" (Determination, patience, confidence, knowledge can help you persist in the face of new challenges and unknown experiences.)
- "Have you ever done something new and wondered if you might not be able to do it? What made you keep trying?"

3. Student reflection activity: The lesson concludes with a wrap-up activity that asks students to either:

    - Draw pictures of a similar experience they may have had when they succeeded even though someone said they couldn't. Have students describe the picture in sentences.

    Or

    - Draw a picture of [something they would like to do but are a little afraid of because they've never done it before]. Have students describe why they are reticent to do the activity and what would help them be more persistent to be successful.

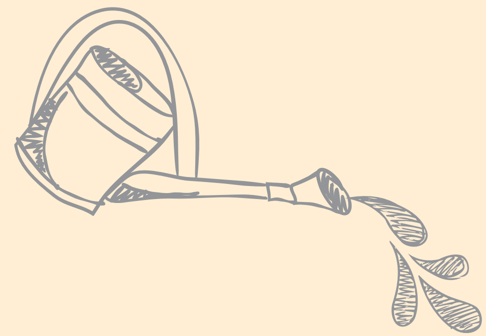
PART II - CURRICULUM CONNECTIONS

Computer Science

1. Seeds at School
The boy was able to care for the seed every day because he planted the seed at home. What would be the difference between being able to take care of the seed if we planted the seed at school? Some things, like watering, need to be done consistently. [What happens when a person cannot do the task consistently, such as when there are weekends or holidays and no one is at school? How could we water the plant when no one is here?]

Explore what students know about [sprinkler systems], a computer-based solution. Why do we have sprinkler systems? Why do some systems have timers? Where is the school sprinkler system? Is there a timer? Have the custodian provide the class with a tour that shows where the timer is, why the school has a timer, and how it works. Where is the controller (computer) on the system?

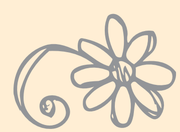
CT Guide on the Side



[Something they would like to do] Attempting a task when the outcome is not completely known requires a sense of confidence that supports finding solutions to problems; confidence dealing with complexity.

[What happens when] Asking the right questions helps to focus the students on a problem that has multiple facets. Asking "how" rather than "who" questions lead students to very different possible solutions.

[Sprinkler Systems]
Highlight Automation: having computers or machines do repetitive or tedious tasks



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This links a practical real-world solution to the problem and also helps students recognize the many hidden places where computers provide solutions.

2. Extensions:

- What happens when it rains? Does the sprinkler system continue to work? How can a sprinkler system sense when it does not need to work? How does it figure out how much water is already in the soil?

- What is the best way to figure out the watering system? Is every day the best way? What about amount of hours? What does a farmer do? These questions can lead to science experiments on under-watering and over-watering. [Using trial and error or a controlled experiment can lead students to learn how a sprinkler system can be optimized to conserve water while adequately watering the plants.]

Science

1. Plant Biology/Science: Based on what was learned in the story, plant a mini classroom garden and care for it from seed to full-grown plants. This could be an outdoor or window-box container garden and could be easily scaled up or down depending on school resources and availability of sunlight. Explore these questions:

   a. "What do we need to grow a plant? Did the boy in the story have everything he needed?" (Make a [list of the resources that are needed and how they can be acquired].)

   b. "What is the [step-by-step process] for planting the garden? What needs to happen first, second, third, etc." (Make a list of the steps. Afix a timeline to the steps based on how much time each would take and when the step should be completed.)

   c. Continue to discuss how the notion of persistence is necessary to complete the goal of planting the garden. "What is making us tired when we think of continuing? What are our worries? What would motivate us to persist? Where are we not doing the best we can? What happens if the plants do not look healthy? What should we do?"

CT Guide on the Side

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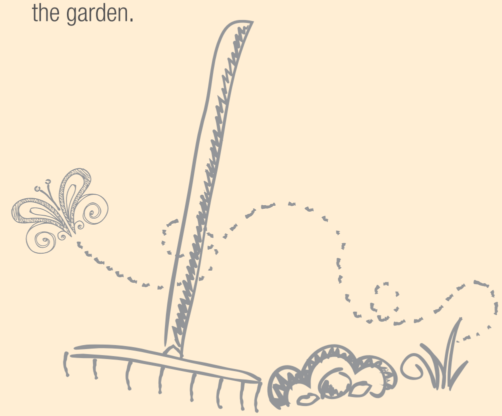
[Using trial and error] Inquiry and trial and error are part of achieving the most efficient and effective combination of steps and resources.

[List of Resources]
Highlight Problem Decomposition: break down task into smaller, manageable parts

[Step-by-step process] Reinforces algorithmic thinking because students must follow a specific order to plant the garden.



d. “What’s the best type of plant for where we live?” (Discuss why plant selection is important. Develop an awareness of how seasons/climate impact plant growth. This is especially important where plants are grown year round and seasons are not as distinct as in the colder climates.)

e. “How do plants grow?” (Plant many seeds. Have students follow the development of the plant by pulling one plant each week so that they may observe the development of the root structure as well as what is seen above ground. Have the students [record the stages] of the plant’s development. Keep [charts and graphs] on the grow rate of the various plants. Consider using a template such as—
Peep and the Big Wide World Neighborhood Safari, “Growing Seeds” found at
http://peepandthebigwideworld.com/printables

Looking at the charts and graphs, have students [draw conclusions from the data]. Is there a pattern between the size of the root and size of the plant? Is there a time frame when the plants grew faster?

Social Studies

Students meet with representatives of organizations that host community gardens (food bank gardens, city gardens, etc.). [Work in groups] to plan a community garden. Have students consider issues that arise when gardening communally:

- Sharing resources (e.g., tools, land, knowledge) with an eye towards fairness. Gardeners could create an electronic calendar that sends out reminders to keep track of who is doing what and when.
- Establish rules about what should (e.g., composting) and should not (e.g., littering) happen in the garden.
- Ask, “What do we want to grow? Why do particular foods grow better in some places than others?” [Study local staples] and find out why they grow well. How does drought or other dramatic climate change impact yield and lead to hunger/famine?

CT Guide on the Side

[Record the Stages]
Highlight Data Collection: the process of gathering appropriate information.

[Charts and Graphs]
Highlight Data Representation: Depict and organize data in appropriate graphs, charts, words, or images.

[Draw Conclusions]
Highlight Data Analysis: making sense of data, finding patterns, making conclusions.

[Work in groups] The ability to communicate and work with others to achieve a common goal or solution.

[Study local staples]
Highlight data collection: the process of gathering appropriate information.

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Reinforces:

Each of the various learning opportunities reinforces multiple aspects of CT.

LITERATURE - Disposition on persistence, sequencing

SCIENCE - Sequencing, creating steps

SOCIAL STUDIES - Working groups, establishing rules, collecting data on food types

Strategies:

Whole-group instruction, questioning strategies, logical thinking to meet a goal, persistence to complete a task.

Transfer:

See activities above as each concentrates on a different curriculum area.

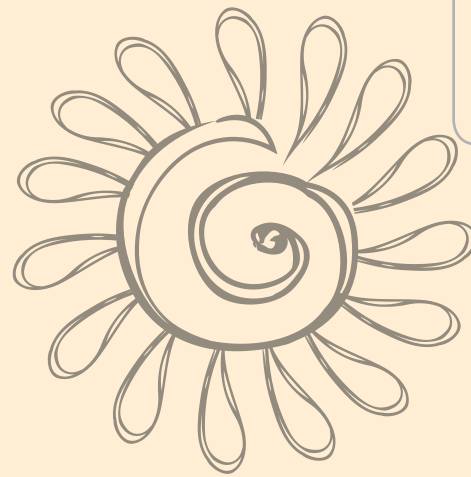
Resources:

1. Since some climates don't enable students to see the full range of seasonal variation or plant life, this is where an interactive simulation of the impact of weather changes on living things could be helpful. Exemplars of these:

   - Weather Transformer: http://pbskids.org/catinthehat/games/weather-transformer.html

   - Web-based graphing tools to chart growth patterns among plants or plant types in the garden: http://nces.ed.gov/nceskids/createagraph/default.aspx

   - SIMS-style garden planning game—Related online games: Flower Finder: http://pbskids.org/catinthehat/games/flower-finder.html



2. Recommended/Related Books—There are many books for both readers and non-readers that show the sequence of plant growth including those that have whimsical plants that talk. Do a search in your library for available resources. Books to look for include:

    - *Tops and Bottoms* by Janet Stevens
    - *Roots, Shoots, Buckets & Boots: Gardening Together With Children* by Sharon Lovejoy

CT Guide on the Side

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Notes:

You can apply the following set of guidelines to all lessons that are geared toward young children and are meant to foster CT skills. Check to see that your lesson delivers the following:

- Encourage thinking in terms of themes (e.g., water play, gardening, building) rather than specific subjects. We know that real-world problems are rarely subject-specific. This approach helps cultivate an interdisciplinary orientation toward problem solving, which enables knowledge and skills to transfer seamlessly to other problems that may need to be solved.
- Nurture meta-cognition. Create moments or related activities that prompt students to think about their own thought process and to consciously recognize elements of CT in their thinking.
- Leverage students' prior knowledge. Relate to a larger classroom project so that knowledge acquired can be applied to a shared set of challenges and tasks.
- Since we rarely solve problems alone, ensure that there are opportunities for students to work together.
- Challenge students in such a way as to create enough tension/ambiguity that they're intrigued about getting to the bottom of it. Enable the educator to explicitly model how one deals with ambiguity.
    - Build in opportunities for students to try, fail, and learn from their mistakes.
    - Require data collection and analysis.
    - Integrate technology when it furthers understanding. Use educational simulations, games, and interactive tools to help students visualize new concepts, plan project-related tasks, and record/collect data.

3 Food Chain

Science Grade 4

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking
- Generalizing and transferring this problem-solving process to a wide variety of problems
- Persistence in working with difficult problems

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This material is based on work supported by the National Science Foundation under Grant No. CNS-1030054.

Outcomes:
Students will create an animation representing the food chain using Scratch.

Standards:
California, Life Sciences, Grade 4

Evidence:

1. Meets: Students create a scene simulating several levels of the food chain.
2. Exceeds: Students create and save multiple scenes showing elements of the ecosystem competing for food.

Activity:

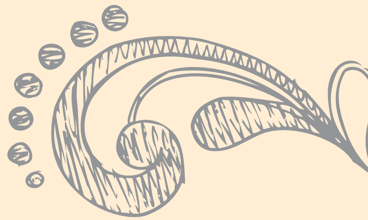
1. As a whole class, students brainstorm characteristics of the following players in the food chain: grass, rabbit, and hawk and [diagram their relationship] in the food chain, which includes the sun and decomposition.
2. Discuss with students various factors that will support equilibrium among the grass, rabbit, and hawk. Extend the discussion to roles that are played by the sun and other animals in the ecosystem. Prompt discussion with these questions:
   a. "If we think beyond these three species, what would make this ecosystem more complex?"
   b. "What are some of the conditions that endanger species in the ecosystem?"
3. Each student creates a simple [Scratch project] that includes a scene of a rabbit eating grass and a hawk taking away the rabbit to demonstrate their understanding of the food chain.

The Scratch program was developed by MIT to teach young students programming

CT Guide on the Side

[Diagram the relationship] The diagram serves as an abstraction of the food chain cycle.

Highlight abstraction: Reducing complexity to define main idea



[Scratch project] The students' work will be a simulation of the food chain

Highlight Simulation: representation or model of a process. Simulation also involves running experiments using the model.

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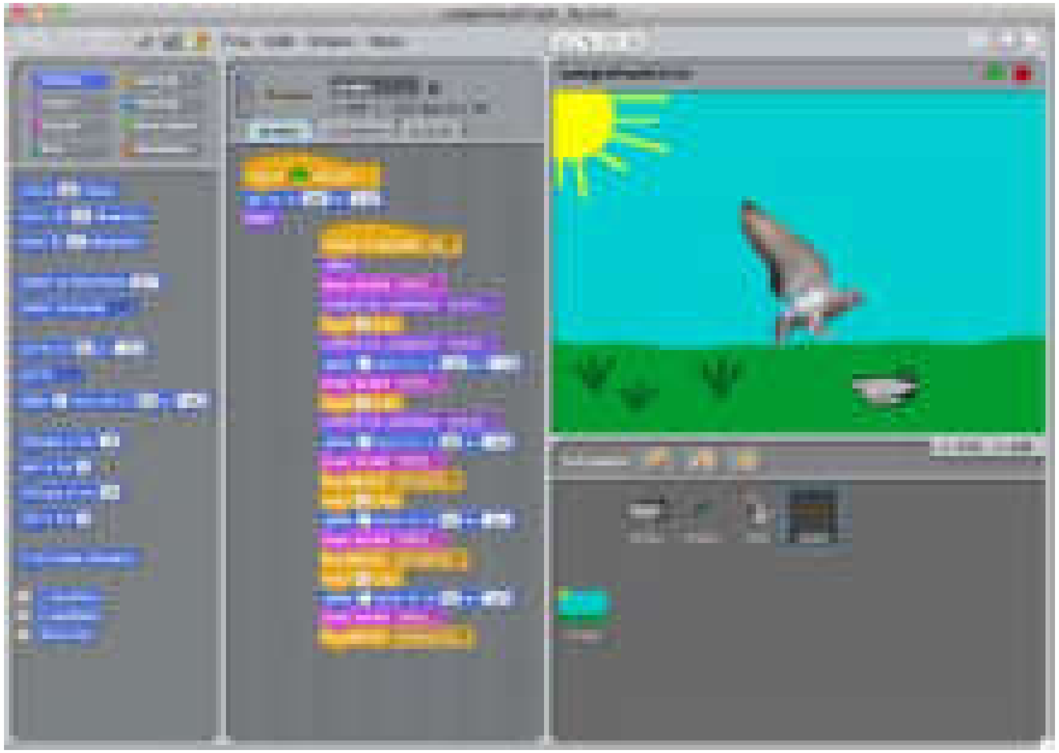
concepts and develop skill in multimedia communication.

Download Scratch (http://scatch.mit.edu/)

Scratch is a rudimentary programming language that makes it easy for students to create their own interactive stories, animations, games, music, and art. Before they begin, they have to [break up their storyline] into pieces—individual characters have specific actions and the characters interact in a specific order. Students have to plan what they want their characters to do, design costumes, and create backgrounds. They begin [creating their animation] of the food chain in Scratch using programming code blocks with commands. Students run the program and test that their animation plays out as intended. If not, they [revise and refine] their program to automate the relationship between the species.



CT Guide on the Side

[Break up their storyline] Students decompose their stories into parts.

Highlight Problem Decomposition: Break down task into smaller, manageable parts.

[Creating their animation] Scratch programming requires students to use algorithmic thinking to ensure that commands are in a specific order to successfully automate a dynamic representation of the concept.

[Revise and refine] Persistence in working with difficult problems.

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4. Students are divided into groups where each group designs an extension to the previously created Scratch project with [additional factors] that impact the food chain. For example, a factor could be additional animals eating the rabbit and causing a food shortage for animals higher in the food chain. Another factor could be the day and night difference to allow plant growth.

Reinforce:

Students must visualize, test, change, and test again to have this system work.

Strategies:

- Have students act out the food chain with their bodies to visualize the system.
- Encourage "guess and check" to have students experiment.
- Use Scratch to do something simple related to prior knowledge. This leads to discussion of the additional factors and variables. Team students up to add complexity to the original Scratch project.

Resources:

Food Chain, habitats: http://www.vtaide.com/png/foodchains.htm

Definitions and visuals: http://www.geography4kids.com/files/land_foodchain.html

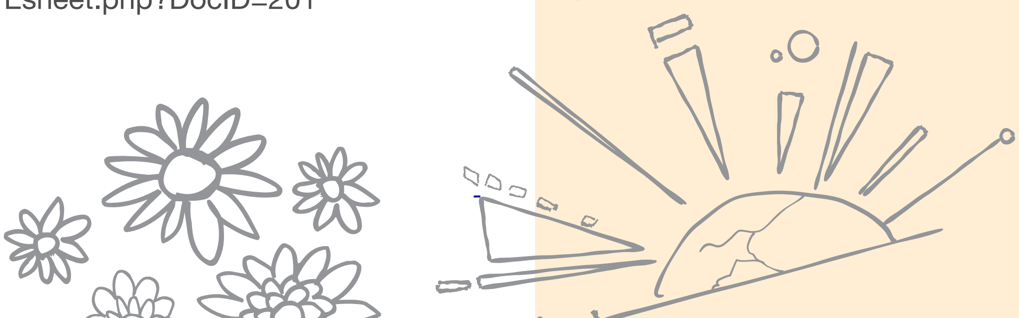
Food Chain: Interactive Game:
http://www.ecokids.ca/pub/eco_info/topics/frogs/chain_reaction/index.cfm

The Cycle of Life: http://www.sciencenetlinks.com/Esheet.php?DocID=201

Scratch Tutorials: http://scratch.mit.edu/

CT Guide on the Side

[Additional factors] By having students extend the activity to reflect more complex systems, this reinforces the concepts to help in transferring this to other problems.



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4 Persuade Me Please

Language Arts Grade 5

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Logically organizing and analyzing data.
- Representing data through abstractions such as models and simulations.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Generalizing and transferring this problem-solving process to a wide variety of problems.
- Able to handle open-ended problems.
- Ability to communicate and work with others to achieve a common goal or solution.

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Outcomes:

- Students will identify the variables in an effective opinion piece.
- Students will determine criteria for an effective opinion piece.
- Students will utilize criteria to create a persuasive essay or opinion piece.
- Students will produce a publishable opinion piece.

Standards:

Common Core Writing Standards, Grade 5, Standard 4
Grade 5, Standard 1

Evidence:

1. Students will collectively develop criteria for an effective opinion piece and illustrate it using a graphic organizer/rubric to assess writing.
2. Students will individually produce and publish an opinion piece that meets the criteria they have set for the genre.

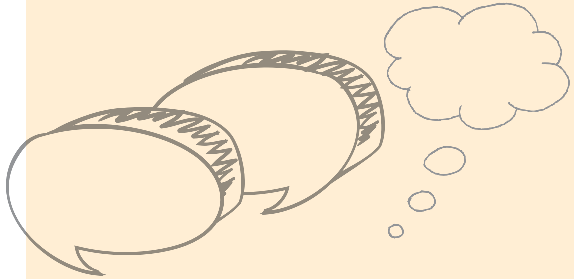
Activity:

Adapted from Read, Write, Think (http://www.readwritethink.org/classroom-resources/lesson-plans/persuading-principal-writing-persuasive-1137.html)

1. Introduce the lesson by telling students they will write an effective opinion piece.
2. Students read and listen to a variety of opinion pieces.
3. Students identify examples of strong and weak persuasive writing and [record commonalities] on a graphic organizer.
4. Class [uses graphic organizers] to generalize criteria for an effective opinion piece and agree on the criteria for a [rubric]. This rubric helps students answer questions:

   How shall I write my piece? What are the [trade-offs]? What are the important things? Are there conflicting criteria?

CT Guide on the Side



[Record commonalities] The process of studying the examples, finding commonalities, categorizing them, and finding patterns helps students to logically analyze and organize data.
Highlight Data Analysis: Making sense of data, finding patterns, and drawing conclusions.

[Use graphic organizers] The software and the resulting chart show a pattern that emerges regarding the characteristics of the opinion pieces in an organized way.
Highlight Data Representation: Depict and organize data in appropriate graphs, charts, words, or images.
Agree on criteria: Ability to communicate and work with others to achieve a common goal or solution.

[Rubric] An abstraction of the criteria for a good opinion piece and informs student decisions about how to write their paper.
Highlight Abstraction: Reducing complexity to define main idea.

[Trade-offs] Students need to make decisions about their opinion piece that balance what is most important with criteria constraints, like word count or structure, to achieve the most efficient and effective combination of steps and resources.

5. Class brainstorms issues in the school or community that they believe deserve action plans.
6. Each group uses a graphic [organizer to explore] the issue. (Find examples of graphic organizers at the Read, Write, Think link on page 29.)
7. Individually, students construct a letter to an appropriate school or community leader addressing the issue.
8. Students use a [word processing] program to draft and edit a letter for grammar/content.
9. Students publish and share with appropriate leaders.

Questions to ask related to the genre:

- Is the author's opinion supported by facts?
- Do the authors use similar vocabulary?
- Are the ideas presented in a logical and sequential manner?
- Is the reader engaged?

Questions teacher asks in the course of the process:

1. What is the problem or task?
2. What are the variables that make an effective opinion piece?
3. How are you going to solve the problem? (Determine a group strategy.)
   - Look for patterns in the essays. How are they similar/different?
   - Decompose the essays into smaller tasks.
   - Identify steps to follow for each of the tasks identified.

CT Guide on the Side

[Organizer to explore] Here the students use a graphic organizer in a new way to explore an issue, rather than come to a consensus on the rubric.

[Word Processing] Help students recognize that spelling and grammar checkers are a feature of word processing automation.

Highlight Automation: Having computers or machines do repetitive or tedious tasks.

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4. How are you going to [represent/summarize your findings] to communicate your thinking?

5. What are some real-world examples of other times you would use this thinking process? Questions related to specific technologies:

    - How can we use technology to help us analyze and organize the documents?
    - How can we use technology to help us edit and publish our final document?
        - Spell check
        - Track changes
        - Embed comments/revisions
        - Add visuals/diagrams that support facts

Strategies:

- Questions asked by facilitator directs students to their thinking process. They require reflection on problem identification, the identification of variables, the selection of thinking strategies, and application to real-world situations.
- Modeling of the following skills is essential to the success of the project: decomposition of a written piece and pattern recognition generalization.
- Probing questions are designed to help students understand how to break down a task, generalize across samples, and organize information to communicate to an audience.

Resources:

See Read, Write, Think link listed on page 29.

Notes:

This activity can be extended by including research into the specific problems to build background knowledge for facts and supporting details. Additional possibilities for incorporating opinion pieces into the curriculum may include analyzing and comparing two pieces of artwork, music, themed stories, or historical events.

CT Guide on the Side

[Represent/summarize findings]
Able to handle open-ended problems.

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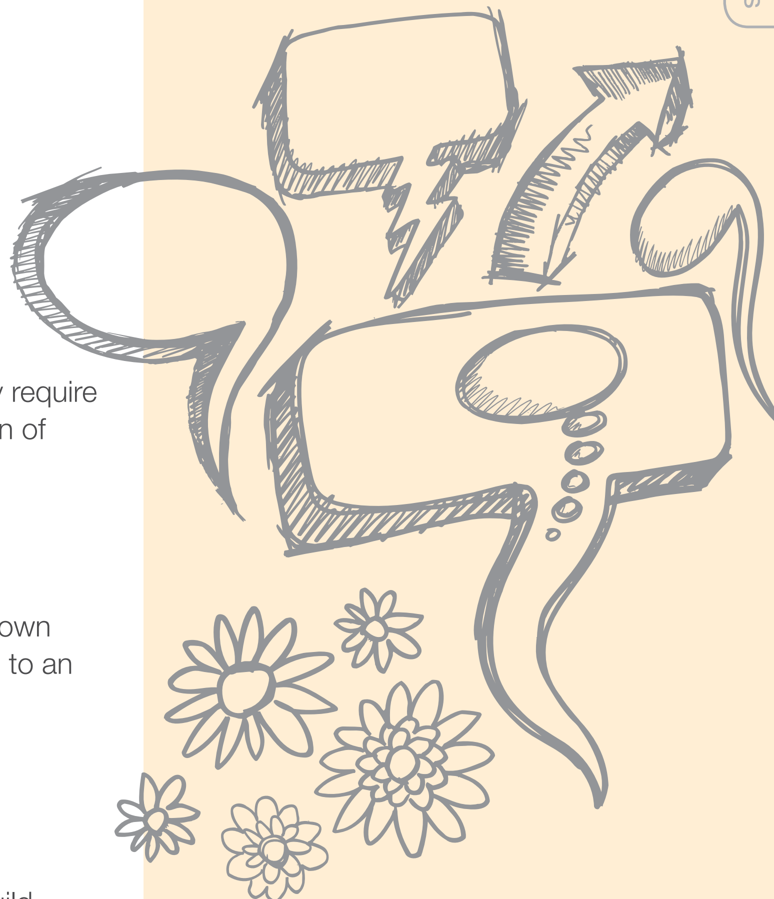

5 Budget Buddy

Social Studies Grade 6–8

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Representing data through abstractions such as models and simulations.
- Logically organizing and analyzing data.
- Automating solutions through algorithmic thinking.
- Generalizing and transferring the problem-solving process to a wide variety of problems.

This material is based on work supported by the National Science Foundation under Grant No. CNS-1030054.

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Outcomes:

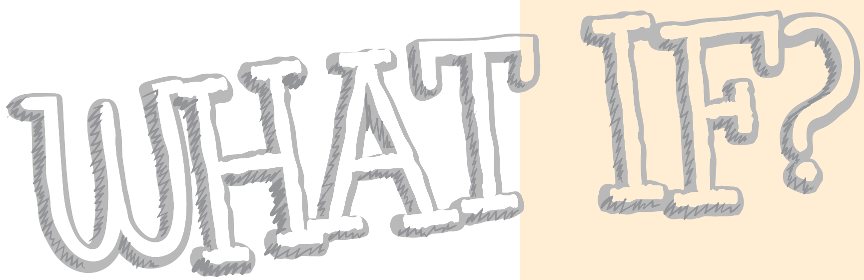
- Students demonstrate the ability to logically organize and analyze financial data in a spreadsheet to help them understand how to budget for a fund-raising project.
- Students demonstrate the ability to use a spreadsheet to create a financial model of a business plan.
- Students demonstrate the ability to conduct “what if” scenarios by altering the financial variables of the project to reflect different circumstances that might be encountered if it is implemented.
- Students demonstrate the ability to create visual representations of the data appropriate for a persuasive presentation to a specified audience.
- Students use the concepts and vocabulary of CT to describe their activities and the resulting spreadsheet.

Standards:

Illinois Learning Standards (Social Studies) and the NETS for Students

Evidence:

1. Students create spreadsheets that organize financial data in logical and appropriate categories, analyze the data, create a business model, generate graphs of the data and manipulate the data to explore several “what if” scenarios based on varying circumstances if they were to implement the project.
2. Students can describe their activities using CT vocabulary including *data representation*, *abstraction*, *model*, and *simulation*.



Activity:

The teacher facilitates a discussion among the students that leads to the selection of a viable fund-raising activity (such as a garage sale, car wash, magazine sale) for their school.

Once they select an activity, the teacher leads a brainstorming session to [create a budget] for the fund-raiser. Appropriate categories are introduced and discussed, including fixed costs, variable costs, income, gross profits, net profits, and the like.

Students create a [spreadsheet] showing the appropriate categories and the hypothetical figures for each category.

Students [label and organize the cateogries and create formulas for the cells] in a way that facilitates the calculation of totals for various sub-categories and categories.

Students label the categories in the spreadsheet in a way that facilitates the creation and discussion of several [“what if” scenarios] to guide decision making based on different circumstances that might occur if the project were to be implemented.

Students create [graphic representations of the data] so they can be used as part of a presentation to the selected audience showing the viability of the project. The class discusses the usefulness of different visual representations (different units of measure, different levels of detail, different colors, and the like) for their own understanding of the data and also for presentation to a different audience (such as their parents) for persuasive purposes.

Strategies:

At this grade range, teachers may want to focus on the core concepts and skills by pre-gathering some data and providing some examples as an introduction. They will also want to be sure students have the requisite technology skills needed to complete the lesson efficiently; however, the main activities here are constructivist in nature. Individual work, class discussion, and individual coaching are likely strategies. Collaborative development of rubrics for the final products would also be helpful.

CT Guide on the Side

[Create a budget] Having students create a financial model for a business activity is a way to represent data through abstractions.
Highlight Abstraction: Reducing complexity to define main idea.

[Spreadsheet] Discuss how formulas and tools within spreadsheets automate calculations.
Highlight Automation: Having computers or machines do repetitive or tedious tasks.

[label and organize the categories and create formulas for the cells] Having students arrange data (and represent it with appropriate formulas) in a spreadsheet to facilitate numerical or visual analysis.
Highlight Data Representation: Depict and organize data in appropriate graphs, charts, words, or images.

[“What if” scenarios] The model with the application of variables creates a simulation that can guide decision making.
Highlight Simulation: Representation or model of a process. Simulation also involves running experiments using the model.

[Graphic representation of the data] Students select and create appropriate visual representations of data for a presentation, and another example of how to represent data through abstraction.

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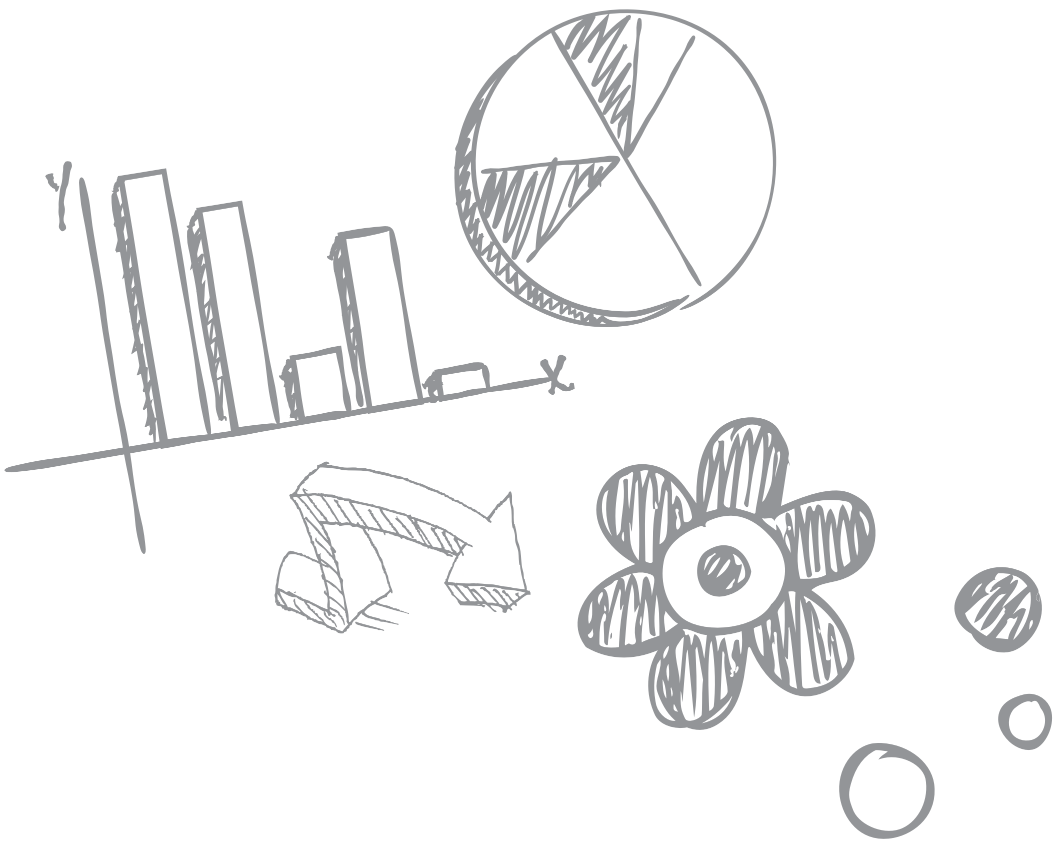
Extensions:

The skills developed in this lesson could be applied to the [development of personal budgets] or to the analysis of more complex budgets for larger organizations such as a corporation or a government entity.

Resources:

Budget Buddy is an online resource for teachers, students, and parents on how to understand and manage money and financial matters.
http://senseanddollars.thinkport.org/games/



CT Guide on the Side

[Development of a personal budget] Students would be able to transfer the problem-solving process to a wide variety of problems.

6 Research Skills

Interdisciplinary Grades 6–8

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Logically organizing and analyzing data.
- Representing data through abstractions such as models and simulations.
- Automating solutions through algorithmic thinking.
- Generalizing and transferring this problem-solving process to a wide variety of problems.
- The ability to communicate and work with others to achieve a common goal or solution.

This material is based on work supported by the National Science Foundation under Grant No. CNS-1030054.

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Outcomes:

1. Students will demonstrate the ability to expand or restrict a set of internet search results by changing the search terms.
2. Students will demonstrate the ability to expand or restrict a set of internet search results by adding Boolean modifiers to the search terms.
3. Students will demonstrate the ability to analyze search results for relevance to a research question.
4. Students will demonstrate the ability to describe the logic of an analysis using pseudocode.

Standards:

AASL's Standards for the 21st Century Learner

Evidence:

Answer the following questions to assess CT:

- Abstraction: Did the search terms yield research articles relevant to the assignment? Were there important articles that were missed because the terms were not abstract enough?
- Data collection and analysis: Did the ratings of the links include false positives or false negatives?
- Algorithmic thinking: Did the pseudocode accurately represent the logic that the students used to make their ratings?
- Algorithmic thinking: Did the teams modify the search terms one at a time so that they would understand the effect of each change independently?
- Algorithmic thinking: Would the pseudocode return a "helpful" or "not helpful" rating for every link?
- Algorithmic thinking: Is another team able to follow the pseudocode logic without further explanation?

Activity:
Introduction

Use of internet search engines has become an essential skill for students. Since searches can return an overwhelming number of results (e.g., as of this writing, using the search term "France" in Google returns more than 1.8 billion links), an important component of search skills is to create efficient search terms. Similarly, search terms can be too restrictive and leave out key articles and information. In this lesson, students will learn how to find a balance between too many results (false positives) and too few results (false negatives).

Note: Change preferences and select "Safe Search" in Google, Bing, and Yahoo to avoid having students discover inappropriate adult sites.

Introduce a search engine

1. As a whole-class activity, select a single word from your current unit and enter it as a search term. Review the results with the class. [Highlight the large number of links] that the search engine returned and the speed of the search.
2. Pick a few of the links to follow, using some that are relevant to the unit and some that are not. Discuss [what the search engine was "thinking"] when it returned the irrelevant links.
3. Ask the class to suggest two search terms that will focus the search on the unit. Try several sets of terms and have the class decide which set gets closest to the topic.
4. Add a third term to the set, then a fourth, etc., until the results center around the topic and the most relevant terms appear on the first few pages. Discuss how the set of search terms now [represents a summary or "abstraction"] of the topic.
5. Demonstrate that we can [eliminate links that result from ambiguous meanings] in the search terms by adding a "-" to the inappropriate term. For example, a search for "oxygen" in chemistry can ignore references to the Oxygen Channel with the words "oxygen -channel."

CT Guide on the Side

[Highlight the large number of links] Search engines are a dramatic example of automation. Have the class consider how much work is involved in finding and listing the links. If the students were doing this manually and were able to find and list one link per minute, it would take them almost 100 years for 50 million listings.
Highlight Automation: Having computers or machines do repetitive or tedious tasks.

[What the search engine was thinking] The term "thinking" is metaphorical. The search engine is following a set of rules or an algorithm on what to include in the search, what to exclude from the results, and in what order to list the links. This algorithm includes roles about where the search term is listed on a page, how many other pages refer to the page, and how many times the terms appear.
Highlight Algorithmic Thinking: Taking a series of ordered steps to solve a problem or achieve some end.

[Represents a summary or "abstraction"] Finding a common element in two or more things and grouping those things based on that element. This is used in computers when we create folders and subfolders for our music, when we decide on what types of information to put into a database, or when we create a spreadsheet formula based on a relative cell option.

[Eliminate links that result from ambiguous meanings] Most search engines allow words or symbols for the Boolean logic modifiers *and*, *not*, and *or*. In fact, *and* is usually implied when two terms are listed.

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Evaluate Search Results

Assign each team of students a research question relevant to the current unit.

Have the teams:

1. Discuss what keywords they will use.
2. Perform a search based on terms that they agree on.
3. [Review each of the links] on the first three pages that result from their search, rating each link as either "helpful" or "not helpful" toward answering their research question.
4. Enter each link and its rating in a word processing table or spreadsheet. [Discuss the advantages that an automated table] has over a simple written list. These advantages would include the ability to cut and paste, sort, count, etc.
5. Identify an additional keyword in the helpful abstracts to add to their query. If they prefer, they could find a term in the non-helpful links to exclude from the search.
6. Execute a search that includes the new term with the previous terms.
7. Review their list of "helpful" links to assure that each is still included in the new results. If not, students should execute another query with a different search term so that they retain all of the helpful links.
8. [Repeat steps 3–9 until they have a list of 20 links] that would be helpful in answering the research question.
9. [Exchange the list and the search terms with another team] and discuss the links that differ on the two lists. Would combining the keywords from the two teams result in a better list?

CT Guide on the Side

[Review each of the links] Data collection is not confined to numerical information. In this case, the teams collect data by analyzing text and creating countable ratings.

Highlight Data Analysis: Making sense of data, finding patterns, and drawing conclusions.

[Discuss the advantages] Highlight Automation: Having computers or machines do repetitive or tedious tasks.

[Repeat steps 3-9 until they have a list of 20 links] Algorithmic thinking includes making changes one at a time so that students can analyze the effect of a single change. Algorithms often include iteration. In this case, each time the team refines the search, each term is a single iteration.

[Exchange the list and the search terms with another team] Computational thinkers have the ability to communicate and work with others to achieve a common goal or solution. (This can involve breaking a complex problem into separate tasks for each team, or as in this case, having teams solve a problem independently then retaining the best aspects of both solutions.

Create a selection algorithm

In this activity, students will reflect on their "helpful" and "not helpful" ratings and create the algorithm that they think they are using. To do this, they will use nested "IF" statements in "pseudocode" very much like a computer programmer would write. If your students are not familiar with writing pseudocode, you can demonstrate the logic you used in the first activity.

For example:

[IF Statements]

- FOR each link returned by search engine:
  - Rate the link "Helpful"
  - IF the link refers to a shopping site THEN rate it "not helpful"
  - IF the link refers to a video THEN rate it "not helpful"
  - IF the link refers to a text page THEN
  - IF the linked page is irrelevant to the unit THEN rate it "not helpful
- Return the results

Reinforces

This activity encourages computational thinking by having students use not only the skills of algorithm design, abstraction, and data analysis, but also to write pseudocode to describe the logic and rules that they created to complete an activity. While each of the CT dispositions or attitudes is important in some aspect of the activity, confidence in dealing with complexity and the ability to communicate and work with others to achieve a common goal are essential for success.

CT Guide on the Side

[IF Statements] Algorithms express the logic and rules of a computer program and are independent of the programming language. Pseudocode is a simulation of creating the actual software code and is used so that the logic can be inspected independently of the programming code.

Highlight Simulation: Representation or model of a process. Simulation also involves running experiments using the model.

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Strategies

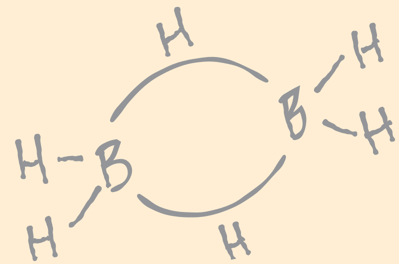
If more time is available, the class should create a rubric to score the relevance of each link rather than restricting a rating to "helpful" or "not helpful." This activity would add a level of abstraction to the lesson since a team would need to define the characteristics of helpfulness to begin their rubric.

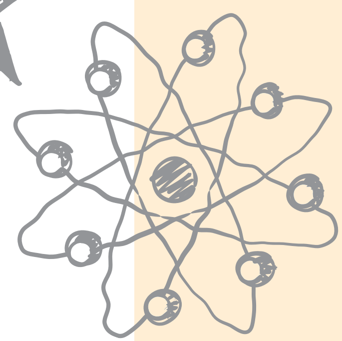
[Using pseudocode to simulate a computer algorithm] is a useful CT skill throughout the curriculum. Some ideas for using pseudocode include:

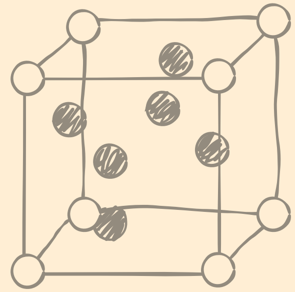
- How will you decide which college to go to?
- Define the scientific process in pseudocode.
- How will my project be assessed?

CT Guide on the Side

[Using a pseudocode to simulate a computer algorithm] By applying this process to another task, students are able to demonstrate that they have generalized and transferred this problem-solving process to a wide variety of problems.







7 Alternatives to the Civil War

Interdisciplinary Grades 9–12

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Automating solutions through algorithmic thinking.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Tolerance for ambiguity.
- Able to handle open-ended problems.

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This material is based on work supported by the National Science Foundation under Grant No. CNS-1030054.

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Outcomes:

- Students will use their understanding of causal factors that led to the Civil War by determining alternate outcomes.
- Students will demonstrate the ability to reconstruct and interpret historic events.
- Students will be able to demonstrate how historic events are interrelated.
- Students will be able to use flow charts to visualize algorithms that represent historical events.
- Students will demonstrate knowledge of logical operations and control structures necessary to solve a problem.

Standards:

Common Core English Language Reading Standards for Literacy in History/Social Studies 9–12

Evidence:

In assessing the CT, answer the following questions:

1. Abstraction: Did the definition of *critical issue* encompass all of the issues that each student submitted?
2. Parallelization: Did the teams that worked on different parts of the problem work together to ensure that the work could be combined as a final product?
3. Algorithmic thinking: Did the flow charts accurately describe the range of alternatives available?
4. Algorithmic thinking: Are there any decision points where the question would need more clarification (e.g., A decision point worded, “Most people want to abolish slavery.” would not be clear since it would require definitions of the word *most* and, in 1860, the word *people*.)
5. Algorithmic thinking: Does each decision point (i.e., each diamond on the flow chart) account for all possibilities? Usually this is handled by the “No” path continuing to further actions or decisions.

6. Algorithmic thinking: Is another team able to follow the logic without further explanation?

Activity:
Introduction

When we view historic events, we tend to view each decision and action as an inevitable step on a path to the actual outcome. The U.S. Civil War, however, is different. Historians still do not agree on which of the economic, social, and political issues of the time were essential ingredients in the conflict. After 150 years, the basic reasons for the war are still disputed by some. In fact, the name of the war itself is controversial: It has been referred to as the War Between the States, War of the Rebellion (used by the Union army), the War of Secession, the War for Southern Independence (used by the Confederate Army), the War of Northern Aggression (used by some modern-day southerners) and the Freedom War (used by some African Americans).

Similarly, the causes of the war are disputed and thoughts often follow geographic divisions. In this unit, students will study the issue "What caused the U.S. Civil War" by imagining different courses that the two sides might have taken had key events been different. The students will construct the basic outline of an adventure game to show how the war might have been avoided or accelerated had different decisions or actions occurred earlier.

1. Identify key events
   Students research the issues that led to the start of the U.S. Civil War with the goal of identifying at least five of those issues as the most influential in the lead-in to the war. Students [brainstorm the characteristics] a *critical issue* should have and then refine those characteristics into a set of characteristics that they will look for in all of the issues that they identify.

   Note: Because the causes of the Civil War are often disputed from a partisan standpoint, student teams could be assigned to do their research to support a Southern or Northern position.

   Next have the class review all of the lists of key issues and events. When the same issue is stated in different ways (e.g., Northern industrialization vs. Southern agrarianism) the

CT Guide on the Side

[Brainstorm the characteristics] The skill of abstraction can be introduced by showing that "finding characteristics" of something is called "determining the properties" of an object in computer sciences.

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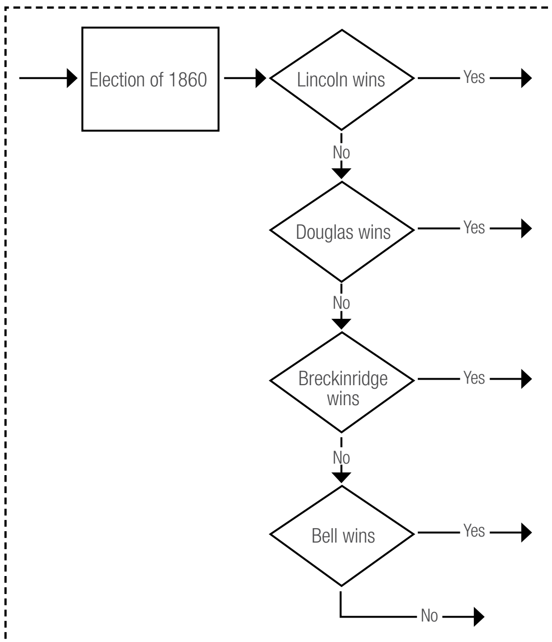
students should find a way of expressing the issue that encompasses both. [Students should analyze the list] by applying the criteria for critical issues, and the class should agree on the 5 to 10 issues that match the best.

2. Identify alternate events for each of the key events
   a. Discuss [adventure games and video games] with the class. The discussion should focus on what the game, and therefore, the author and programmer must anticipate when the player makes a [decision]. Have a student describe a scene in a game he or she has played then review that scene to find all of the decision points that occur. Create a flow chart to show that each of these decisions creates an alternate path that the player will take. Point out that some of these paths may converge again and some may end before the goal is reached.
   b. Discuss the critical issues of the U.S. Civil War in the context of an adventure game. At each of the critical points the "player" (in this case the player is a Southern state) had an [option to take a path] different from the one that led to the Civil War. Where would that path have led?
   c. Break students into groups with each group [identifying the possible alternatives] to the path taken to a particular critical issue.
   d. Choose one of the critical issues and demonstrate to the class [how to create a decision] (also called a conditional) on a flow chart. One path should duplicate the historical record (e.g., Lincoln wins the election of 1860) while the other paths should represent all of the alternatives.



CT Guide on the Side

[Students should analyze the list]
Highlight Data Analysis: Making sense of data, finding patterns, making conclusions.

[Adventure and video games]
Games are a form of automation in that a computer delivers narrative in a structured, decision-based way. Class discussion should focus on other forms of automation that are similarly hidden, such as online searches, cell phone contact lists, etc.
Highlight Automation: Having computers or machines do repetitive or tedious tasks.

[Decision] Use the term here instead of "move" to emphasize the algorithmic thinking that the game programmer must use.
Highlight Data Analysis: Making sense of data, finding patterns, and drawing conclusions.

[Option to take a path] The abilities to handle open-ended problems and to tolerate ambiguity are essential to choosing a particular alternative. Discuss how to handle these ambiguities by developing a strategy for choosing an alternative path to follow. These strategies might include a team vote or a rubric.

[Identifying possible alternatives] Point out to the students that most computer applications are developed in a similar way, with teams typically working in parallel on components of the application then merging the components into a final result.

[How to create a decision] Stress to the students that in algorithms, decisions are usually binary (e.g., either Lincoln won or did not win). If there is more than one alternative path at any point, the alternatives should be sorted by a series of decisions (e.g., if Lincoln did not win then Douglas either won or did not win; if Douglas did not win then Breckinridge either won or did not win; etc.).

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3. Follow a path to an alternate outcome
   Each team of students will [create a flow chart] from a specific critical issue and map where at least one of the paths might lead. Their goal should be to determine whether the alternate path would have made the U.S. Civil War more likely, less likely, or equally likely. After completing the flow chart, each team will write a narrative that describes the "new" history.

4. Combine alternate paths
   As a whole-class activity, [combine the alternate paths] from each of the teams. Some of the alternate paths may merge during this activity (i.e., an alternative at each of two critical points would lead to the same path) and some may join the path that history followed.

Reinforces

This activity encourages CT by having students use not only the skills of algorithm design, abstraction, and working in parallel, but also use flow charts—one of the most important tools of an application designer. While each of the CT dispositions or attitudes is important in some aspect of the activity, students' tolerance for ambiguity and their ability to work with open-ended problems are essential for success.

CT Guide on the Side

[Create a flow chart] This activity is a simulation very much like a computer model would employ to predict the outcome of a current election. Similar models are used for weather forecasting, military strategy, etc.
Highlight Simulation: Representation or model of a process. Simulation also involves running experiments using the model.

[Combine the alternate paths] When technical designers develop computer applications, they look for pathways that will merge so that work does not get duplicated by any team. This is another aspect of parallelization.
Highlight Parallelization: Organize resources to simultaneously carry out tasks to reach a common goal.

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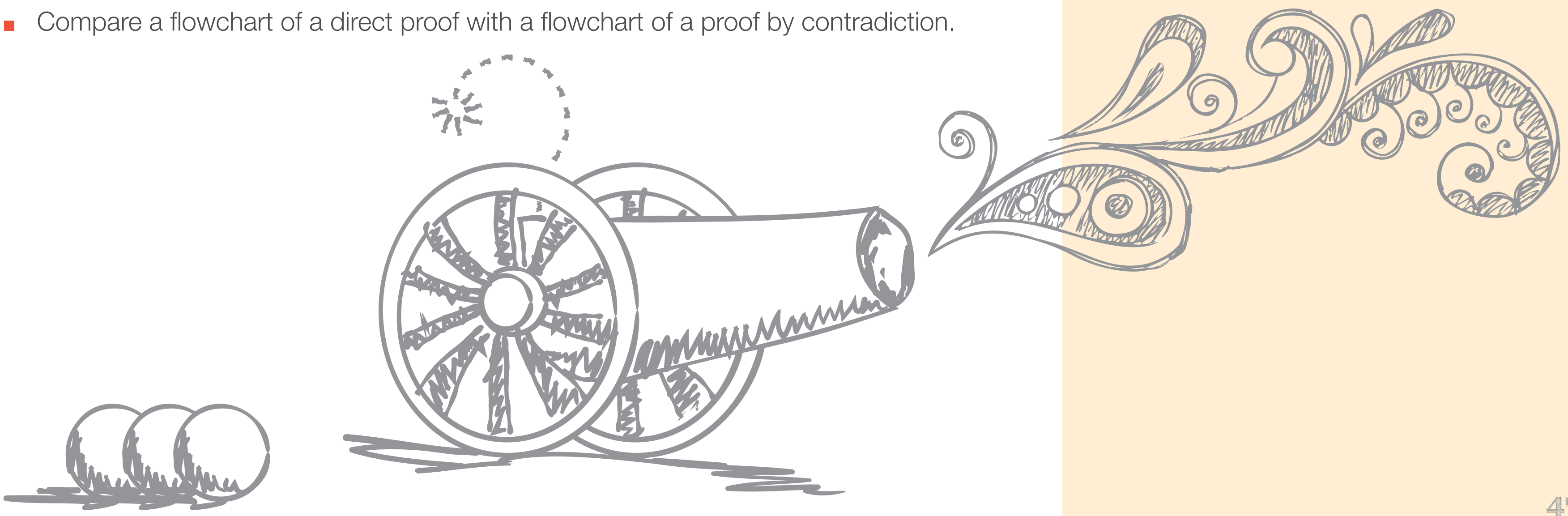
Strategies

Students should be instructed in basic flowchart symbols (input, output, processing, decision-making).

If time is limited, the class could take a single critical issue, such as the election of 1860, and have all students work with it. Individual teams would take each of the alternatives (e.g., Breckinridge won) and build a flow chart from there.

Using flow charts to simulate alternate paths is a useful CT skill throughout the curriculum. Some ideas for adapting this lesson include:

- If Hamlet had been more decisive and killed Claudius as soon as he knew he was guilty, how might the play have ended?
- How would the world be different if water contracted instead of expanded when it froze?
- Had DDT not been banned, what would the local environment be like?
- Compare a flowchart of a direct proof with a flowchart of a proof by contradiction.



8 Traffic Jam

Interdisciplinary Grades 9–12

Appropriate for Humanities, Social Studies, Environmental Science, or Mathematics

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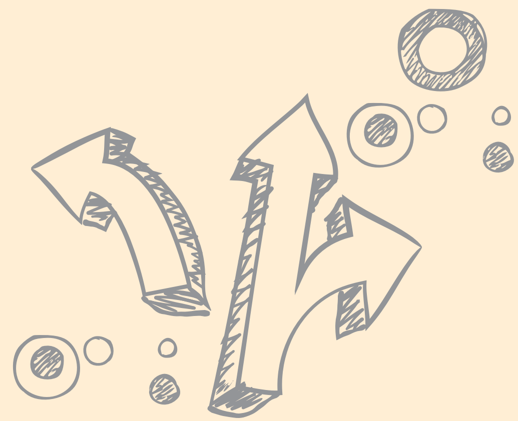
CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Representing data through abstractions such as models and simulations.
- Logically organizing and analyzing data.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Confidence in dealing with complexity.



Outcomes:

- Students will be able to represent relationships between different real-world variables.
- They will propose changes in variables that can help make a solution more efficient.

Standards:

Common Core English Language Writing Standards

Common Core Math Standards

New York State Science and Social Studies standards

Evidence:

1. Students will show that they can construct a conceptual model (computer based or paper based) of the relationships between the variables affecting the problem. Have students explain their process and understanding of the model they created.
2. Students will demonstrate their ability to identify sub-components of the system and interdependence; identify special cases and outliers in the data from their simulation, and the cause of those outliers.

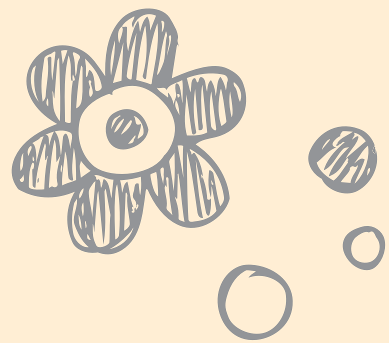
Activity:

This is designed as a small group project.

1. Define a [complex problem] in your community involving traffic. This could be a bottleneck in the hallways of your school in between classes, a traffic problem with automobiles in your community, or persistent delays at a local airport. This example is an automobile traffic problem at a local high school. This activity can be adapted for a variety of situations.

CT Guide on the Side

[Complex problem] Confidence in dealing with complexity.



Problem statement:
At a local school there is only one entrance to the driveway that leads to the front of the school. All vehicles are required to drive through this entrance to drop the students off at school in the morning. There are 1200 students at the school and the majority of them are driven to school with only one student in each car. Traffic enters the driveway from both directions, which forms a T intersection with the school. Vehicles make a right or a left turn to the school driveway and there is no traffic light, stop sign, or crossing guard at the entrance. This causes excessive traffic back up and safety issues during peak hours.

2. Break students into small work groups and task them with [identifying variables that have caused the problem]. Some variables could be the number of students in the school, a lack of car-pooling, lack of multiple entrances, student behavior, community culture, town planning issues, administrative decisions, legal issues, or school scheduling.
3. Students should [create a map or diagram] that illustrates the properties that match the variables in the problem. A paper map or diagram could also be used. Using the variables the students identified, they should mark up the map with the various variables they identified as causing the problem.
4. Students should, in parallel, collect data and do research on the variables they identified as causing the traffic problem. This research could involve [data collection] at the source of the problem, surveys, interviews, and web-based research.
5. Define relationships among all of the variables. Each group will [create a model] that shows the interdependency of the identified variables. The model may be diagram, map, graphs, or 3D, and could be computer-generated.
6. Students should put together a portfolio of graphical representations of the relationships of their variables. They can use a variety of types of graphs and charts (e.g., pie charts, bar charts, graphs, maps, etc.).
7. [Estimate the influence] of each variable by giving it a magnitude scale. Likely variables for system: number of students vs. number of cars, age of drivers, time waiting in traffic, schedule, numbers of entrances, local traffic codes, etc.

CT Guide on the Side

[Identify variables] In doing this, students are formulating the problem as variables, or they could do the same with a questioning technique that has consequences for how they approach the problem.

[Create a map or diagram] This represents the data students have been given.
Highlight Data Representation: Depict and organize data in appropriate graphs, charts, words, or images.

Highlight Data Collection: The process of gathering appropriate information.

[Create a model] the model will be an abstraction of the variables and data they collected.
Highlight Abstraction: Reducing complexity to define main idea.

[Estimate the influence] Students will be analyzing their data.
Highlight Data Analysis: Making sense of data, finding patterns, and drawing conclusions.

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8. Each group will show and describe how the model will [change if a variable changes] (e.g., adding an entrance to the school, staggering school schedules).

9. Students should research and study which variables can be changed and how difficult it is to change them. They should form a hypothesis of what the effects of changing some of the variables might be, and how the outcome will change. This will help them learn about the interdependence of the variables at hand.

10. The group should write up and create a presentation of their findings.

Extension: Have the class agree and [defend one optimal solution], with the understanding that this might not be the best solution. Present the optimal solution to the school administration and school board to influence change in their school.

Reinforce:

The goal is for students to realize the thinking process is still the same even with computer and technology changes. Instructors should have students reflect on what thought processes and skills were used to solve this problem. Students should be guided toward "variables, modeling, data analysis, data collection, relationships, and dependencies." Discussion should then lean toward where else such thought processes and skills might be applied or where else students may have accomplished similar thinking patterns. It would also be helpful for students to discuss other problems that could benefit from the same process they completed in this activity.

Strategies:

Provide the students with a framework for brainstorming a solution to a problem. Ask leading questions about the resources at hand, the stakeholders, causes, and effects. Teach students ways to visually organize information in a meaningful way (e.g., Venn diagrams, entity relationship diagrams, graphs, maps, flowcharts). Provide students a resource to research visual representation methods. Provide examples of how this concept or these capabilities/skills could transfer to other disciplines or the solutions for other problems. Reinforce problem-solving and group-work techniques as necessary.

CT Guide on the Side

[Changing variables] When students work with changing variables or multiple "what if" situations, they are doing simulations.
Highlight Simulation: Representation or model of a process. Simulation also involves running experiments using a model.

[Defend one optimal solution] This will be a culmination for the students of their analysis of the problem and how they came to the most efficient and effective solution.

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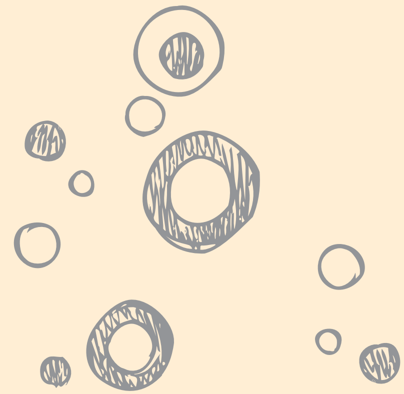


Resources:

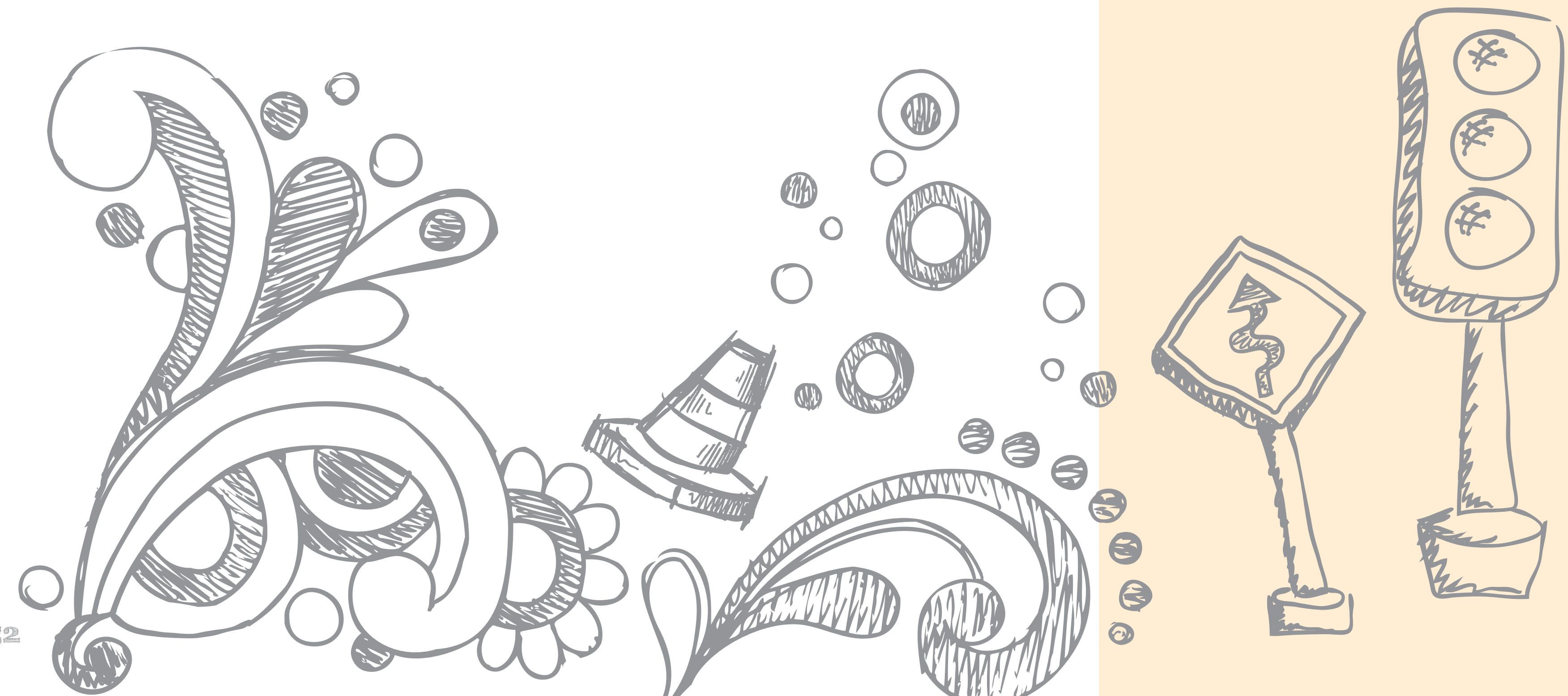
Use Google maps to study the physical location.

Use Google docs—spreadsheet, presentation, sketch-up, and document—to collaborate and visually represent problem.

Flow chart tutorial: http://www.mindtools.com/pages/article/newTMC_97.htm

Tools for graphically seeing relationships for cause and effect: Seeing Reason http://educate.intel.com/en/thinkingtools/seeingreason/ and Text2Mindmap.com http://www.text2mindmap.com/

This lesson can be done without a computer.



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Notes:

This activity may be adapted to other disciplines by choosing open-ended problems to be resolved with multiple solutions. This lesson highlights a thought process that allows the students to take a complex system, break it into smaller components (variables), and explore system relationships in an effort to find a solution to their problem. They will have taken an abstract problem and come up with a practical solution. This problem cannot be solved without thinking in a logical manner. By adding simulation to this project, students will learn what happens when they change one of the variables they identified. They can learn if changing a variable makes the situation better, worse, or causes other previously unknown problems. This problem is unique in teaching students to reflect on their solution and improve on their design. At the end of this lesson, students consciously understand that they have used CT to solve the problem. They also realize that this skill is transferable to other disciplines. This can be used as a lesson plan for a substitute teacher. A good idea would be for the teacher to have a rubric that insures students know what skills or vocabulary they need to acquire. Some of the places the CT skills acquired in this activity can be applied, include the chemistry classroom (changing variables in a chemical solution), environmental science (studying effects of human created pollutants on the environment), public advocacy (how a government controlled situation can change based upon community input), computer science (have students write programs to model and analyze a variety of situations), mathematics, economics, careers, or journalism.

9 Conway's Game of Life

Computer Science Grades 9–12

Appropriate for a computer science classroom after students have mastered basic programming skills.

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Engage

CT Guide on the Side

CT skills and dispositions included in this learning experience:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Representing data through abstractions, such as models and simulations.
- Automating solutions through algorithmic thinking (a series of ordered steps).
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Confidence in dealing with complexity.
- Persistence in working with difficult problems.
- The ability to communicate and work with others to achieve a common goal or solution.

Outcomes:

1. Students will be able to implement the basic algorithms developed by Conway in describing the Game of Life to animate cellular reproduction models.
2. Students will explore various cellular patterns to determine their behavior.

Evidence:

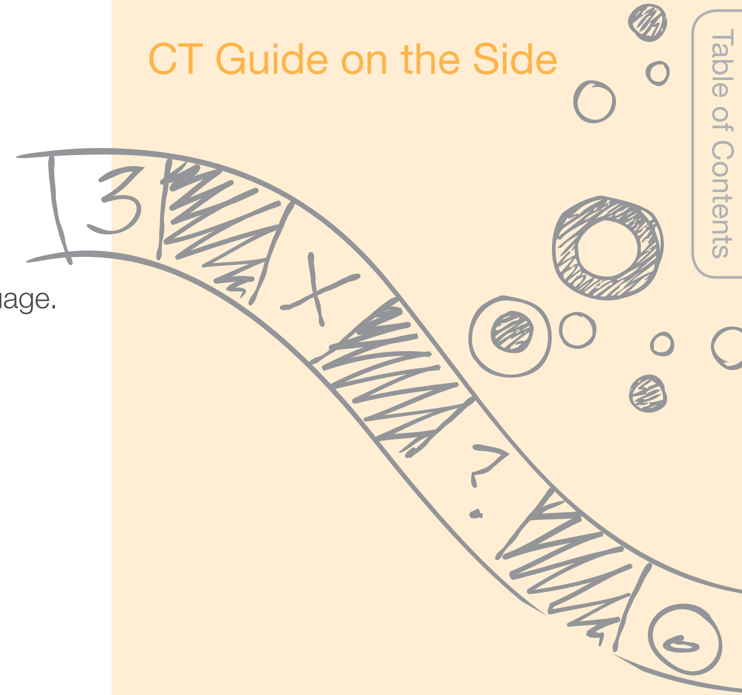
1. Students will implement the Game of Life using an appropriate programming language.
2. Advanced placement students should implement the solution using the GridWorld framework, which provides a useful graphical user interface (GUI) for displaying the results.
3. Students will explain how Gliders are generated based on the behavior of the Glider Gun.
4. Students will develop flow charts, pseudocode algorithms, or solution outlines.

Activity:

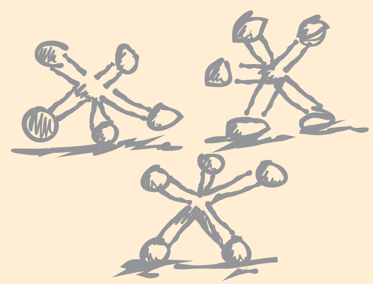
Stages 1 through 3 are designed as a small group project.

1. Research Conway's Game of Life. [Prepare a short paper] (two to three pages) on the topic that would be suitable for publication in an appropriate professional magazine or journal. Pick at least three websites that you can use to answer the following questions as you conduct your research:
   a. How is the Game of Life different from a typical computer game?
   b. What are the basic rules of the game?
   c. Describe the kinds of objects that emerge in Game of Life, such as still life objects, oscillators, and gliders. Do not limit your discussion to just these objects.
   d. Why is using a computer an appropriate solution to this problem?
   e. What other types of problems could be studied using simulations based on the Game of Life?
   f. Is Game of Life alive?

CT Guide on the Side



[Prepare a short paper] This activity helps develop the students' abilities to communicate and work with others to achieve a common goal.



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2. Using graph paper and the rules of the Game of Life, [explore the behavior] of one still life object, one oscillator object, and one glider object. Clearly illustrate the behavior of the object though one complete cycle of its existence (until it returns to its original pattern).
3. Prepare a brief PowerPoint presentation that combines the results of your research and your graph paper exploration. [Present the results] of your research to the class.

Individual programming component: Students should fall into one of the following categories:

1. Advanced Placement Students:
   [Implement the Game of Life] using the GridWorld framework. One approach would be to create a Cell object, which extends a Rock to represent a living cell. These Cell objects would be placed in the world to create the appropriate cellular pattern being explored. Then create a CellChecker object that extends Bug. The CellChecker object checks each grid location and applies the rules to create the next generation. Remember that the rules are applied to the existing configuration before any cells die or are born. Other approaches may be used to achieve similar results.
2. Other Computer Science Students:
   Implement the Game of Life using a two-dimensional array to represent the world. Use a character, such as "O," to represent a living cell. Then check each grid location and apply the rules to create the next generation. Remember that the rules are applied to the existing configuration before any cells die or are born. Display the results of each generation on the computer screen.
3. After you have successfully tested your program, turn in your computer code. Ensure it is fully commented and properly formatted. Include screen shots of various stages from several of your objects.

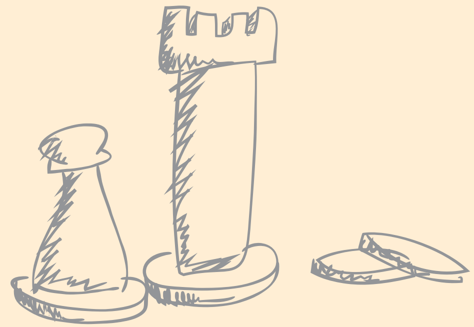
Extension: Have the class [review the different solutions] and determine if one solution is optimal. If an optimal solution is not found, are there components of several solutions that could be combined to create an optimal solution? Discuss why the optimal solution might not be the "best" solution.

CT Guide on the Side

[Explore the behavior] By using pencil and paper, the students can start to understand the rules of the game and possible moves. This helps identify the steps that will describe (algorithmic thinking) the solution.
Highlight Algorithmic Thinking: Series of ordered steps taken to solve a problem or achieve some end.

[Present the results] This activity strengthens the students' ability to communicate the results of a technical investigation.

[Implement the Game of Life] Games are a form of automation in that the computer delivers narrative in a structured, decision-based way. Class discussion should focus on other forms of automation that are similarly hidden, such as online searches, cell phone contact lists, etc.
Highlight Automation: Having computers or machines do repetitive or tedious tasks.



[Review the different solutions] As students review the different solutions to this problem, they can begin to grasp the CT concepts of achieving the most efficient and effective combination of steps.
This demonstrates persistence in working with difficult problems.

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Reinforce:

The goal is for students to realize that the thinking process used to solve this problem was the same for both the paper and pencil exercise and the programming exercise. Students developed algorithms, applied those algorithms to existing conditions, and achieved similar results in each case. Students should realize that the computer is a tool that helps us implement solutions developed by human beings.

Strategies:

Provide the students with a [framework for brainstorming] solutions to the problem. Ask leading questions about the rules, behaviors, and programming constructs. Allow students to interact with each other during the programming process to illustrate that computer science has a social as well as individual component. Students should [develop flow charts, pseudo code algorithms, or solution outlines] prior to beginning coding so that they demonstrate a full grasp of the problem. They should also recognize that changes to their initial design may become necessary as they move from design to the implementation phase of the project.

Resources:

A quick Google or other search engine search reveals numerous references on the Game of Life and several include java files. Students should be discouraged from copying these files and using them as their own. Only as a last resort should students refer to these files, and then they must give credit to the source, recognizing that this is not their own work. Students should have been exposed to several design techniques throughout their course, and should refer to notes or other references if more information on flowcharts or algorithm development is required.

Notes:

This is an example of an activity that originally did not involve a computer as part of the solution, but certainly involved many aspects of CT in the development of the rules and playing of the game. Conway originally developed the Game of Life using a Go Board and Go pieces to represent the cells. Students may be familiar with the board game Othello, which could be used to illustrate the game before making the assignment.

CT Guide on the Side

[Framework for brainstorming] The skill of abstraction can be introduced to begin this by showing that "finding characteristics" of something is called "determining the properties" of an object in computer sciences.

[Develop flow charts, pseudocode algorithms, or solution outlines] This activity is a simulation very much like a computer model would employ to predict the outcome of a current election. Similar models are used for weather forecasting, military strategy, etc. Highlight Simulation: Representation or model of a process. Simulation also involves running experiments using the model.

E | Middle School Scenario

This scenario illustrates how a teacher can reinforce computational thinking (CT) skills and dispositions in a problem-based learning unit. Virtually all the CT skills and dispositions are involved at some point in this problem. In addition to showing how individual CT skills can contribute to the solution of complex, real-world problems, the unit also demonstrates how the whole set of skills and dispositions can work together to make the problem-solving process more efficient and effective.

What CT Looks Like in the Classroom

Last Spring, North Fork Middle School was flooded when the North Fork River that runs alongside the school grounds overflowed after several days of torrential rains, doing serious damage to the building and its contents. Since the river had never overflowed before—even in similar weather conditions, there are many theories concerning why it happened and what can be done about it. The mayor and city council of North Fork are planning to hold hearings on the causes and possible solutions to mitigate such flooding in the future and have asked for public input.

Ms. Janson is going to conduct a six week–long problem-based learning unit that uses a constructivist approach—engaging her middle-school students in gathering information, analyzing options, and proposing solutions to mitigate future flooding based on the best data available. She knows that to be taken seriously by the city council, her class's proposals will have to be based on sound data, show logical analysis, and be presented in ways that can be clear and persuasive to their audience. She also recognizes that CT skills will be essential to their success, and she plans to use the project to help her students develop and use these skills and to understand that they can be used in many other problem-solving situations in school and in their future careers.

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Project Activities

Ms. Janson kicks off the unit by asking her students to create a concept map of the possible causes of the recent flooding problem. She explains that creating a concept map is a kind of **problem decomposition** that will help them describe the most important components of the flooding problem and explore how they relate to each other. She also reminds them that this is an open-ended problem that probably won't have a single, clear answer. They will need to keep an open mind about possible causes and solutions and resist reaching conclusions too quickly.

The concept map is then used to facilitate the creation of a Know/Think, We Know/Need to Know (K/TWK/NK) chart that the students can use to decide what research needs to be done and how they might divide the work so that teams can meet their deadline for a presentation to the city council. Ms. Janson uses the concept map and K/TWK/NK chart to help her understand her students' thinking so she can provide formative feedback.

Ms. Janson points out that there are many opinions in the community about both causes and solutions to the flooding problem, but that the city council has indicated they need evidence-based presentations to help determine the best course of action. The concept map they created shows that this is a complex, systems problem with many possible contributing causes and an almost overwhelming amount of data that could be considered. The **problem needs to be formulated** in a way that will help them focus on appropriate data gathering, processing and presentation, including the use of computer tools and digital resources.

Ms. Janson asks her students, "What tasks can be automated to help us gather and analyze data most efficiently and effectively?" Using the K/TWK/NK chart, they make a list showing what data may be available in a digital format that would enable them to organize and analyze it using automated processes. When they discover that city and county agencies have a wide range of data captured before and during the recent flood, students make a list of the data available, the sources and formats, and size of the data collections. Ms. Janson helps them create a matrix based on the data that enables them to identify how data **collection and analysis might be automated** to save time, perform automated pattern recognition, and generate reports that might be used in their presentation.

While the availability of data in electronic format will be essential, Ms. Janson uses the concept map and K/TWK/NK chart to generate a list of other kinds of data that they will need to construct a complete picture of the flood event and to consider causes and solutions that might not be evident from the electronic data. Students decide to **collect additional data** through interviews of eye-witnesses to some flood events (such as the blockage of channels under bridges). The class discusses and generates protocols for conducting interviews. Students also discuss automated capture and organization of the data. As a whole, the class begins to create rubrics for assessing the quality of the data collected and the efficiency of the analytical approaches.

Given the quantity and diversity of the data, Ms. Janson facilitates a discussion of **the ways the data can be represented** to find patterns, identify inter-relationships among the parts of the system, and create the models and simulations (that students can use to conduct "what if" scenarios to explore both causes and solutions). She introduces them to various kinds of **"abstractions"** of the data, such as representing the data using models and simulations. Such abstractions can be used to represent complex systems in a more manageable way that can facilitate understanding and exploration.

Middle School Scenario

Based on the kinds of data to be used and the representations selected, Ms. Janson guides the teams toward **the creation of appropriate models** that might help them understand causes and investigate possible solutions. These might include physical mockups, pictorial representations, mathematical models, and computer-based data models. Each team is challenged to select and justify a model that will help with their individual task. She then helps the teams set up a collaborative online space where they can share their models, offer helpful criticism, and begin to work together toward their common goal. Since the flooding took place over a period of time, students will use the models to **conduct simulations** of changes in water flow and level under a variety of different and changing conditions. Ms. Janson facilitates a discussion of the various factors that might have contributed to the flooding: rainfall duration, pattern of rainfall in the area and upriver, flow of water through the river channel, resistance and blockages, elevations of river banks, and overflow areas. The class simulated possible solutions—building levees and berms, channeling water to existing lakes and ponds, and limiting construction in the flood plain, and restoring wetlands.

Students introduce strategies for organizing the results of the simulations for further analysis and for presentations using spreadsheet data and visual representations as examples. They also include calculations of costs/benefits into spreadsheets and organize them to facilitate analysis. The class discusses likely community responses to various solutions and generates options for **organizing data** for the presentation.

Teams **analyze existing data** to calculate the probabilities of various scenarios, including the likelihood of future flooding and acceptance by the community of costs to prevent flooding damage (via polling data). Students then discuss tradeoffs of costs and benefits and strategies for presenting them to the city council.

At the beginning of the unit, Ms. Janson introduced the class to the concept of **step and resources optimization**, and the class set up a project plan using software for efficient resource allocation, including the use of parallel processing. Ms. Janson and her students regularly reviewed their project planning charts to track their process and consider mid-course corrections as needed to reflect actual events and availability of actual resources.

Finally, the whole class works together to create a presentation for the city council, describing their findings about possible causes and recommendations for possible solutions.

Once the unit has been completed, Ms. Janson conducts a debriefing where she asks students to reflect on a number of questions designed to help them clarify what they have learned and how that learning might be **generalized and transferred** to other problems in the future. Her questions focus not only on skills, but also on attitudes they felt were needed to accomplish their goals, such as persistence, tolerance for ambiguity, and confidence in dealing with complex problems. She also asks students to identify careers in which this kind of problem solving is likely to be used.

Ms. Janson uses this data to document the work of the class as part of an action-based research project that she will share with other teachers in her school and district and to refine the unit for use in the future.

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How CT skills work together

When planning the unit, Ms. Janson looked for opportunities to teach or reinforce individual CT skills, but she also created opportunities or teachable moments to help students learn how CT skills can work together synergistically. She wanted her students to learn that added power can be gained from understanding and using their inter-relationships and interactions (using CT skills as a package).

Here are some examples of how she highlighted the relational power of CT skills.

When facilitating the creation of a concept map, Ms. Janson asked students whether the ideas they generated for possible causes of the flooding included possible causes that could be modeled, pointing out that digital modeling might contribute to the efficiency of the exploration of cause. She pointed out that the use of digital as well as physical models could help them state their cases clearly and effectively to their audience by making it more visual.

When facilitating the exploration of models, she asked whether they could think of models that would enable them to run simulations of a variety of "what if" scenarios showing changes over time.

When facilitating the gathering of data, she encouraged them to explore the availability of digital data that would enable them to automate the collection and organization of the data and also its use in digital models and simulations.

When organizing the data, she asked which organizational strategies would most likely help them with the subsequent analysis of the data.

Throughout the unit, Ms. Janson continually asked her students to reflect on the strategies they had selected so far and how they might be refined to ensure that they worked together efficiently to achieve the most effective results. These "meta-cognitive moments" provided opportunities for her students to take a systems approach not only to a problem they were investigating, but also to the problem-solving process they were using.

Understanding the relationship and interactions among the skills used in the problem-solving process is an esssential part of building effective problem-solving skills, but they are not always made explicit. Teachers can help students leverage the power of CT skills by calling attention explicitly to how they can work together as well as how they can be generalized to other problems and applied across disciplines.

Ms. Janson made sure that these opportunities were included in the sample rubric criteria that she used as a starting point for discussion as the class developed their own rubrics for formative and summative assessment. During discussions she also asked questions about the way CT skills are inter-related to make the relationships among them clear and explicit so students would incorporate them into their thinking.

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F High School Scenario

This scenario illustrates how a teacher can reinforce computational thinking (CT) skills and dispositions in a problem-based learning unit. Virtually all the CT skills and dispositions are involved at some point in this problem. In addition to showing how individual CT skills can contribute to the solution of complex, real-world problems, the unit also demonstrates how the whole set of skills and dispositions can work together to make the problem-solving process more efficient and effective.

Rethinking a Unit to Include Computational Thinking

Like every year, Marla Sanders came home from the annual technology conference energized. Besides picking up countless tips and tricks that will help her in her history classes at Mountain View High School, she was intrigued by a concept that was new to her. In a session that her department head recommended, she learned about CT and how important it is to her students.

Ever since she started teaching in 1998, Marla has been committed to a student-centered approach. She includes critical thinking components in each of her projects and assesses her students on those skills. Marla suspected that she could emphasize CT in some of these projects without major changes. If she added some steps or even simply changed the emphasis of some of the activities, she thought she could help her students immensely.

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She started with a meeting with Erin Paulson, her Social Sciences department head, who had been a long-time mentor to Marla. Since it was Erin who steered her toward CT, Marla thought that her insights would be valuable. Marla was also not confident in her computer science skills, so she thought some help with some of the concepts such as "algorithmic thinking" would help.

Getting Started

Erin's first piece of advice was to pick a project that Marla already planned to change. This turned out to be easy. Marla has been teaching a unit on migration that incorporates U.S. census data, and she planned to make changes based on the results of the 2010 decennial census.

The project that students do within this unit is her modification of a lesson on the growth of U.S. cities. She combines this lesson with some of the activities from a U.S. Census Bureau lesson plan on the 2010 census. In the project, her students research both national and state events and plot those events against national, state, and city population data. Marla and Erin decided to start with the list of CT skills and to look through the unit for an authentic opportunity to teach or emphasize each of the skills.

They began with *data collection, data analysis*, and *data representation*—what they called "the easy ones" because the project already focused on data. In one activity the students compile historical census data to explain the growth or decline of urban areas. They compare the data with historical events and demonstrate the relationships with a timeline. Marla added a discussion of how the Census Bureau collects data and ensures its accuracy. To make the data representation section stronger, she added an activity in which students use the same data set, but chart it differently to emphasize or de-emphasize a point.

The *abstraction* CT skill was a bit harder since there were no current activities that explicitly addressed that skill. Erin and Marla turned to the census reports to look for examples of abstraction. They found a report on "Housing Quality" and when they looked at how quality was operationally defined, they knew they had their activity. To start the activity Marla would brainstorm a list of characteristics of high-quality and low-quality houses. Then the students would develop a set of questions to ask respondents to determine the quality of the house they lived in. The whole class would then look at the questions that the Census Bureau uses to determine the quality of a house in the *American Community Survey*. Next Marla would tie this discussion into the migration unit by discussing the importance of lifestyle improvement in the motivation to move one's family to a new city.

Erin suggested they look at the *automation* CT skill next because having students think about how technology can help them solve problems is a major goal of CT. Because Marla is a history teacher, she pointed out that much of the early history of computing was influenced by the overwhelming size of the census data set. She decided to have her students review the Census Bureau's technology web page and divide into teams to argue which census-related technology has changed their lives the most. She will instruct the students that their arguments should include an explanation of how the relevant problem was solved before the invention.

High School Scenario

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The *parallelization* CT skill demanded some thought. While Marla believes in a team approach to problem-solving, she had not included any activities in this unit where—primarily because each activity is brief. It was Erin's idea to team with Jerome Duncan, the math teacher, for the visual representation of data. Teams in his class could serve as graphic service providers to the teams in Marla's class. The history students would supply the data sets and the math students would provide the charts from those data sets. Marla planned to talk to the class about how this collaboration between specialist teams is the most common problem-solving arrangement in the business and scientific worlds. Erin agreed to chat with Jerome to make a case why this project is important enough to make room for it in his math class.

As Marla looked through her unit for an example of the *problem decomposition* CT skill, she realized that it was all around her. Each of the activities had several tasks to be done and required at least a minimal amount of planning. She decided to simply point this fact out to her students and to talk about how much more complex a task like the decennial census is.

Finally, Erin and Marla tackled the *algorithms* and *procedures* CT skill. This skill proved difficult for them since Marla did not feel comfortable with an activity where students actually created algorithms. Erin encouraged her to simplify by looking for an existing activity. She found a website that explained how to create a flowchart for a census count and included a link to the site in her project bookmarks. She will have her class review the site and invite her students to actually create a flowchart for extra credit.

While both agreed that the *simulations* CT skill is important to CT, Erin thought that they had tackled enough in this unit. Marla agreed and expressed her fear that adding a simulation would take up more time than she had budgeted and might remove the emphasis from human migration. She knew she had other units that could be modified with a better fit for a simulation.

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Follow-up

After Marla completed her changes to the unit and tried it out in the fall, Erin asked her if she would prepare a case study to present at the next faculty training day. Marla agreed. Besides, she already planned to put something together for the next annual conference.

In her presentation Marla used the CT operational definition as a framework for describing her project:

Computational Thinking—Formulating problems in a way that enables us to use a computer and other tools to help solve them.

- Logically organizing and analyzing data
    - If your student projects already include collecting and analyzing data then emphasize the role of automation.
    - The automation occurs at many levels from large national databases, to Google searches, to local storage and analysis, to charting.
- Representing data through abstractions such as models and simulations
    - You probably do this already too. When we go from specific cases to generalities, we are abstracting.
    - In my project we looked at how specific cities grow and shrink to reach conclusions about how all U.S. cities grow and shrink.
- Automating solutions through algorithmic thinking (a series of ordered steps)
    - Again, you include this in your teaching so emphasize CT by using the term “algorithm” when you do.
    - It can be as simple as having students reflect on the process that they used in a project.
    - Developing rubrics for assessment when they are using algorithms.
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
    - In the census project, explore different ways of representing data to tell the most accurate story.
    - Automation allows us to explore other ways of telling the same story.
- Generalizing and transferring this problem-solving process to a wide variety of problems.
    - I am proof that you don’t need to be a computer scientist to include computational thinking in your teaching.
    - All fields now have some computational element so all students will need CT professionally.

G | CT Resources for K–12 Educators

Many computational thinking (CT) sites focus on higher education or research; however, this list of resources is for classroom teachers across disciplines; the one exception being Jeannette Wing's seminal article on CT, which first proposed CT skills for all students.

If you know of or want to share resources that K–12 teachers can use in their classrooms, please send them to computational-thinking@iste.org to be included in an updated edition of this booklet. Please note that resources will be vetted before inclusion in this list.

Article by Jeannette Wing

Computational Thinking, an article by Jeannette M. Wing, published in March 2006, first proposed CT as a foundational skill for all students.
http://www.cs.cmu.edu/afs/cs/usr/wing/www/publications/Wing06.pdf

Computational Thinking WebQuest

A teacher's introduction to computational thinking with ideas for implementation.
http://www.edci.purdue.edu/lehman/ct/teacher.html

Computer Science For Fun

Puzzles and games that develop CT skills.
http://www.cs4fn.org/algorithms/swappuzzle/

CS Unplugged

http://csunplugged.org/activities
A collection of free learning activities that teach computer science through engaging games and puzzles that use cards, string, crayons, and allows students to move.

CS4HS: Resources

Ideas, approaches, and activities for cultivating computational thinking and computational creativity in your classroom.
http://cs4hs.media.mit.edu/resources.html

EcoScience Works

A computer-based curriculum, focused on environmental science and computer programming, developed for 7th and 8th grade students as part of the state of Maine laptop program.
http://simbio.com/Maine

Google's Exploring Computational Thinking

Google Education has developed free CT resources for use in the classroom.
http://www.google.com/edu/computational-thinking/

Google's math and science activities

https://docs.google.com/document/edit?id=1oq_ZGTXwLh9AES7a0-L2k92UilYBwm4ZuOCCKmM4j1M&hl=en&pli=1&ndplr=1

Model Behavior: Computational Thinking in Computer Science at Girls Middle School

An example of 3-D modeling and design for middle school students.
http://www.girlsms.org/node/938

Novel Games: Good Games for the Whole Family

Fun online games that help develop CT skills.
http://www.novelgames.com/flashgames/game.php?id=54&l=e

Shodor Foundation

Shodor Foundation focuses on computational science and develops free, web-based resources.
http://www.shodor.org/activities/

COMPUTATIONAL THINKING

teacher resources second edition

For more information, visit iste.org/computational-thinking or write to computational-thinking@iste.org.

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